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An overview of the Petite Amateur Navy Satellite (PANSAT) project

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Monterey, California

THESIS

AN OVERVIEW OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT) PROJECT

by

Fred J. Severson

December, 1995

Thesis Advisor:	I. Michael Ross
Co-Advisors:	Daniel Sakoda
	Todd Morris

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AN OVERVIEW OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT) PROJECT

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Submitted in partial fulfillment of the
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ABSTRACT

The main thrust of this thesis is to present a manageable document that accurately portrays the current state of PANSAT and its supporting infrastructure. Research efforts involved investigating a variety of aspects of the PANSAT program including chronology, design, decision processes, and operations. The program objectives include the role of the PANSAT project as an educational tool for officer students and as a proof of concept for a small, digital store-and-forward communications satellite. An extensive list of external agency documentation requirements is also included. Scholastic institutions conducting similar projects could use this thesis as a design guideline as well as to spearhead their documentation efforts. This thesis is meant to be a comprehensive document as well as a suitable starting point for information concerning the PANSAT program.

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LIST OF ABBREVIATIONS, ACRONYMS, AND/OR SYMBOLS

The following list consists of abbreviations, acronyms and/or symbols that were encountered during the course of the research for this thesis. Although not every acronym is used in the thesis, their inclusion may prove beneficial during the course of further research.

A/D	analog-to-digital
AFB	Air Force Base
AFD	Aft Flight Deck
AFIT	Air Force Institute of Technology
AFS	Air Force Station
AFSCN	Air Force Satellite Control Network
AGC	Automatic Gain Control
Ai	Artificial Intelligence
AM0	Air Mass Zero
AMSAT	Amateur Radio Satellite Corporation
AOR	area of operation
ARPA	Advanced Research Projects Agency
ARRL	American Radio Relay League
ARTS	Automated remote tracking station
ASIC	Application Specific Integrated Circuits
ASTRO	Army Space, Technology and Research Office
BBS	Bulletin Board Services
bps	bits per second
BER	Bit Error Rate
BIT	Built-in Test
BOL	Beginning-of-Life
BPSK	Binary Phase Shift Keying
BSFR	Back-Surface Field and Back-Surface Reflector
C&DH	Command and Data Handling Subsystem
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAP	Complex Autonomous Payload

CAP	Crew Activity Plan
CARS	Customer Accommodations and Requirements Specifications
CASE	Computer Aided Software Engineering
CCAFS	Cape Canaveral Air Force Station
C_d	Coefficient of Drag
CDMA	Code Division Multiple Access
CDR	Critical Design Review
CFR	Code of Federal Regulations
CG	Center of Gravity
CIR	Cargo Integration Review
CITE	Cargo Integration Test Equipment
CLIPS	C Language Integrated Production System
cm	centimeter
CNC	Computerized Numeric Control
COMM	Communications
COTS	Commercial off-the-shelf
CP	casualty procedures
CPR	Customer Payload Requirements
CPU	Central Processing Unit
CRC	Cyclical Redundancy Check
CSOC	Consolidated Satellite Operations Center
CST	Comprehensive System Test
CSTC	Consolidated Satellite Test Center
CUL	Space Test and Small Launch Vehicle Programs Office
DARPA	Defense Advanced Research Projects Agency
dB	decibel(s)
DCS	Digital Communications (or Control) Subsystem
Det	Detachment
DFR	Direct Funded Research
DFVT	Data Flow Verification Test
DMA	Defense Mapping Agency
DOC	Documentation
DOD	Department of Defense
DOD	Depth-of-Discharge
DOF	Degrees Of Freedom

DOT	Department of Transportation
DPS	Data Processor and Sequencer System
DPSK	Differential Phase Shift Keying
DRAM	Dynamic Random Access Memory
DSCS	Defense Satellite Communications System
DSI	Defense Systems Incorporated
DSP	Defense Satellite Program
DSSS	Direct Sequence Spread Spectrum
DSTS	Deep-space tracking system
EDAC	Error Detection and Correction
EE	Electrical Engineering
EHF	Extremely High Frequency
EIRP	Effective Isotropic Radiated Power
ELV	Expendable Launch Vehicle
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EOL	End-of-Life
EPS	Electrical Power Subsystem
ESA	European Space Agency
ESTL	Electronic Systems Test Laboratory
ETE	End To End
ETR	Eastern Test Range
eV	electron volt
EVCF	Eastern Vehicle Checkout Facility
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCIP	Fracture Control Implementation Plan
FDMA	Frequency Division Multiple Access
FEA	Finite Element Analysis
4-FSK	Four Frequency Shift Keying
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects, and Criticality Analysis
FOC	Final Operating Capability
FOV	Field of View
FRR	Flight Readiness Review

FSK	Frequency Shift Keying
ft.	foot, or feet
FTA	Fault Tree Analysis
GaAs	Gallium Arsenide
GAS	Get-Away Special
GEO	Geosynchronous Orbit
GFE	Government Furnished Equipment
GHz	Gigahertz
GNC	Guidance, Navigation, and Control
Gp	processing gain
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSTDN	Ground-Space Tracking and Data Network
GTDS	Goddard Trajectory Determination System
GTO	Geostationary transfer orbit
HB	Handbook
HH	Hitchhiker Program
HMDA	Hitchhiker Motorized Door Assembly
HP	Horsepower
HPA	High Powered Amplifier
HPF	Hazardous Processing Facilities
HST	Hubble Space Telescope
I&T	Integration and Test
IAP	Integration Activities Plan
ICBM	Inter-Continental Ballistic Missiles
ICD	Interface Control Document
IDD	Interface Definition Document
IFOV	Instantaneous Field of View
ILS	Integrated Logistics Support
in.	inch(es)
INC.	Incorporated
I/O	input/ouput
IOC	Initial Operating Capability
IR	Infrared

IRS	Interface Requirements Specification
IST	Integrated System Test
ITU	International Telecommunications Union
IVT	Interface Verification Test
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
k	thousand
kbps	kilobits per second
KHB	Kennedy Handbook
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
lbs.	pounds
LEO	Low-Earth Orbit
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LPR	Low Probability of Recognition
LSA	Launch Services Agreement
LSSP	Launch Site Support Plan
MAC	Modal Assurance Criteria
MB	megabyte
Mbps	megabits per second
MCC	Mission Control Center
Mcps	Megachips per second
MDF	Manipulator Development Facility
MDP	Maximum Design Pressure
MHz	megahertz
MICD	Mechanical Interface Control Drawings
MIL	Merritt Island Launch
MIPS	millions of instructions per second
ML	Materials List
MM	Minuteman
MMD	Mean Mission Duration
MOA	Memorandum of Agreement
modem	modulator-demodulator

MOE	Measures of Effectiveness
MSD	Mass Storage Device
MSLS	Multi-Service Launch System
MTBF	Mean Time Between Failures
mux	device, multiplex
N63	Navy Space Systems Division
NAG	Navy Astronautics Group
NASA	National Aeronautics and Space Administration
NASDA	National Space Developmental Agency (Japan)
NAVEMSCEN	Naval Electromagnetic Spectrum Center
NDE	Non-Destructive Evaluation
NEC	Numerical Electromagnetics Code
NiCd	Nickel Cadmium
NM	nautical mile(s)
NORAD	North American Aerospace Defense Command
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NSTS	National Space Transportation System
NSTSO	National Space Transportation System Office
NTIA	National Telecommunications and Information Administration
OBC	On-board computer
OFS	Orbital Functional Simulator
OMI	Operations and Maintenance Instructions
OMRS	Operations and Maintenance Requirements and Specifications
OP	operating procedures
OPF	Orbiter Processing Facility
OPN	Open Purchase Navy
OSCAR	Orbiting Satellite Carrying Amateur Radio
OTH	Over-the-Horizon
PAML	Project Approved Materials List
PANSAT	Petite Amateur Navy Satellite
PAPL	Project Approved Parts List
PAR	Payload Accommodations Report
PBBS	packet bulletin board system
PC	Personal Computer

PCB	Peripheral Control Bus
PCB	Printed Circuit Board
PCB	Primary Control Board
PCM	Pulse Code Modulation
PCR	Payload Changeout Room
PDR	Preliminary Design Review
PED	PANSAT Engineering Documents
PI	Program Introduction
PI	Principal Investigator
PIP	Payload Integration Plan
PM	Phase Modulation
PM	Project Manager
PN	Psuedo-Noise
POC	point of contact
POCC	Payload Operations Control Center
PPF	Payload Processing Facilities
PQM	Phase Quadrature Modulation
PRF	Pulse Repetition Frequency
PROM	programmable read-only memory
PSF	Payload Servicing Facility
PSK	Phase Shift Keying
PSRP	Payload Safety Review Panel
QA	Quality Assurance
QPSK	Quadrature Phase Shift Keying
rad(s)	radian(s)
R&D	Research and Development
RAM	Random Access Memory
REC	receive
RF	Radio Frequency
RISC	Rockwell International Space Corporation
ROM	Read-Only Memory
RMS	Remote Manipulator System
Rx	receiver
SAIL	Shuttle Avionics Integration Laboratory
SAMTO	Space and Missile Test Organization

SATCOM	satellite communications
S/C	Spacecraft
SCB	Secondary Control Board
SCC	Serial Communications Controller
SCOS	Spacecraft Operation System
SDP	Safety Data Package
SDR	System Design Review
SDRC	Structural Dynamics Research Corporation
SERB	Space Experiment Review Board
SFP	Space Flight Plan
SGLS	Space-Ground Link System
SI	International System of Units
SID	System Integrated Development
SIP	Standard Integration Plan
SIVP	Structural Integrity Verification Plan
SIVR	Structural Integrity Verification Report
SMC	Space and Missile Center
SMC/CUL	SMC/Space Test and Small Launch Vehicle Programs Office
SMWG	Structural/Mechanical Working Group
S/N	Signal-to-noise ratio
SOC	Satellite Operations Center
SOCC	Spacecraft Operations Control Center
SOG	satellite operations group
SOH	State of Health
SOW	Statement of Work
SPA	Small Payloads Accommodation
SPF	Software Production Facility
SRAM	Static Random Access Memory
SRP	Safety Review Panel
SRR	System Requirements Review
SS	Spread Spectrum
SSAG	Space Systems Academic Group
SSC	Space Surveillance Center
SSN	Space Surveillance Network
SSCP	Small Self-Contained Payload

SSPP	Shuttle Small Payloads Project
SSR	Software Specification Review
STAR	Space Thermoacoustics Refrigerator
STD	Standard
STDN	Spaceflight Tracking and Data Network
STEDI	Student Explorer Demonstration Initiative
STP	Space Test Program
STPI	Spacecraft Test Probe Interface
STS	Space Transportation System
SVTL	Safety Verification Tracking Log
S/W	Software
T&E	test and evaluation
TAPR	Tucson Amateur Packet Radio
TBD	to be determined
TDMA	Time Division Multiple Access
TMUX	Temperature Multiplexer
TNC	Terminal Node Controller
T/R	transmit/receive
TRR	Test Readiness Review
TSC	Test Support Complex
TSPI	Time Space Position Information
TT&C	Telemetry, Tracking and Command Subsystem
Tx	transmitter
UDS	Universal Documentation System
UHF	Ultra-High Frequency
USAF	United States Air Force
USAFA	United States Air Force Academy
USN	United States Navy
USNA	United States Naval Academy
USRA	Universities Space Research Association
UTC	Universal Time Coordinated
UV	Ultraviolet
VAFB	Vandenberg Air Force Base
VHSIC	Very high speed integrated circuit
VLA	Verification Loads Analysis

VTL	Verification Tracking Log
VTS	Vandenberg Tracking Station
WBS	Work Breakdown Structure
WSMR	White Sands Missile Test Range
WTR	Western Test Range
WVCF	Western Vehicle Checkout Facility
WWW	World Wide Web

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I. INTRODUCTION

A. WHAT IS PANSAT?

PANSAT is the acronym for the Petite Amateur Navy Satellite, which is a small communications satellite (see Figure 1.1) that has been under development since 1989 by the Space Systems Academic Group (SSAG) at the Naval Postgraduate School (NPS). The SSAG is an interdisciplinary association of academic departments at NPS that manages and fosters the space systems curricula and directs and sponsors space research. Residing under the auspices and sponsorship of the Navy Space Systems Division (N63), PANSAT provides opportunities for hands-on system design, hardware and software development, system integration, testing, and operational studies and exists primarily for the education of the officer students stationed at NPS. These students hail from diverse backgrounds, representing all branches of the military services as well as numerous foreign countries, and are actively involved in virtually all aspects of the program, including design, development, ground support operations, and on-orbit operations. Satellite launch, as a Shuttle secondary payload via the Space Transportation System (STS) Small Self-contained Payload (SSCP) program, is tentatively planned for September 1997 on STS-86. The actual launch date will be determined by PANSAT's completion date as well as by the STS schedule, with the ongoing program providing invaluable educational opportunities for both present and future NPS students.

In March of 1989, the first of many theses pertaining to PANSAT was published. Shortly thereafter, Daniel Sakoda and J. K. Hiser penned a technical paper [Ref. 1] outlining the satellite which was subsequently included in the National Aeronautics and Space Administration's (NASA) 1989 University Advanced Design Program Conference Proceedings. Representing the small satellite concept, PANSAT emerged in 1989 from the ashes of NPS's ORION satellite program, which was abandoned due to lack of funding. PANSAT is a 150 pound, 26-sided, polyhedral-shaped digital communications

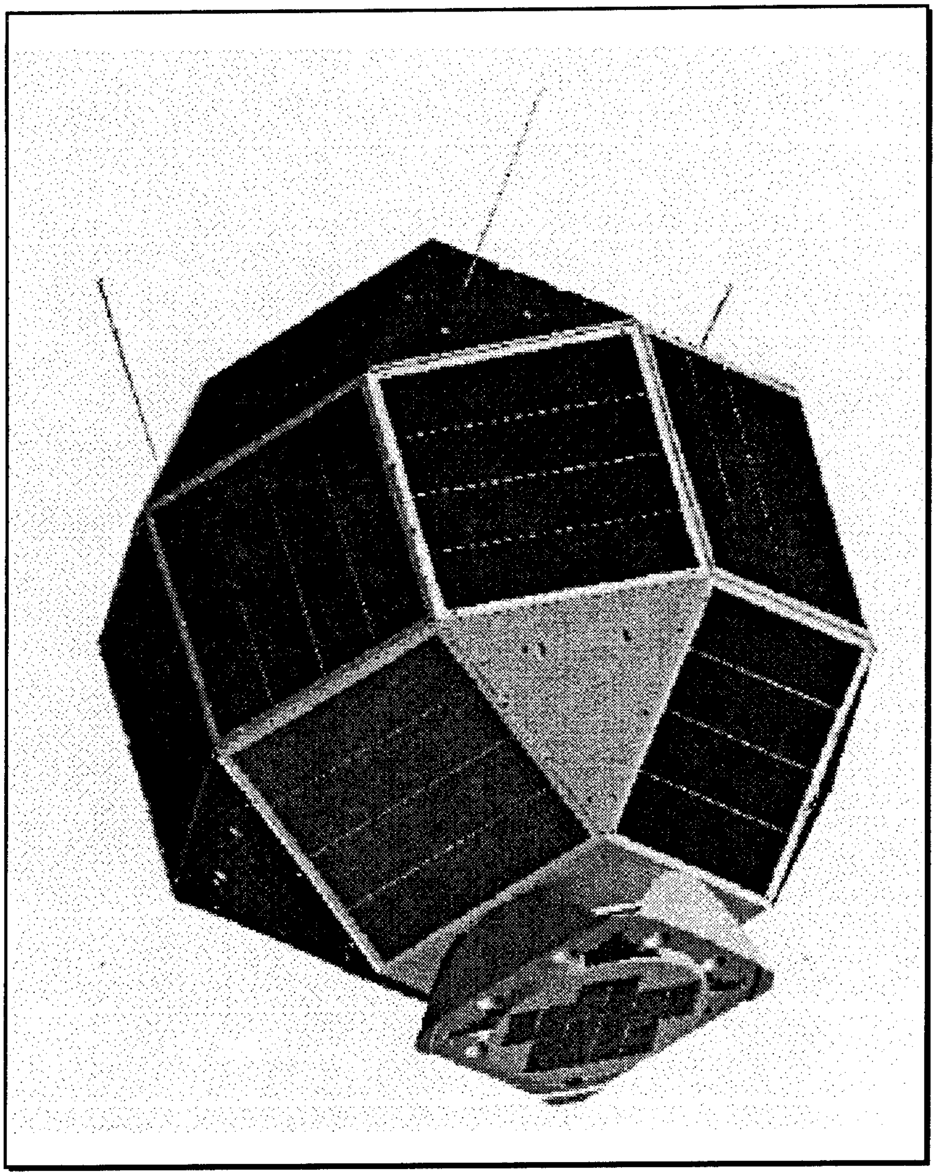


Figure 1.1 PANSAT Representation [Ref. 2]

satellite with one solar panel mounted on the Launch Vehicle Interface (LVI) in addition to the 17 body mounted solar panels. Assuming orbital insertion via STS-86, PANSAT will be launched into an orbit with an altitude of about 210 nautical miles (NM), which is equivalent to 389 kilometers, and an inclination of approximately 52°.

B. REQUIREMENTS AND CONSTRAINTS

Requirements can be separated into two categories and can be defined, along with constraints, as follows [Ref. 3, p. 14]:

- *Functional Requirements* define how well the system must perform to meet its objectives.
- *Operational Requirements* determine how the system operates and how users interact with it to achieve its broad objectives.
- *Constraints* limit cost, schedule, and implementation techniques available to the designer.

A shuttle launch was initially chosen as a baseline for design since shuttle flights are manned and therefore have the most stringent requirements. A number of restrictions relating to safety concerns as well as to compatibility as a secondary payload must be dealt with when requesting a launch from the SSCP program, which consists of the Get-Away Special (GAS) and the Hitchhiker (HH) programs. The NASA GAS canister is used by both launch mechanisms, providing the necessary flight support for small, low-power experiments. SSCP experiments are flown on a space/weight available basis and accordingly must meet strict volume and weight requirements. The conservative nature of the SSCP design constraints enable PANSAT to easily qualify as a secondary payload for other launch platforms, such as Scout and Pegasus. [Ref. 4, pp. 1-3]

The timeline for PANSAT is susceptible to change due to a number of reasons. Design delays, supply shortages, test findings, and STS availability all affect the proposed schedule. Unlike most commercial ventures, educational concerns drive the

pace of the PANSAT program. Educational aspects of the program include volunteer student involvement, thesis research, and continuous student turn-over, which unfortunately leads to a loss of corporate knowledge. In an era governed by shrinking budgets and downsizing in both the military and commercial establishments, PANSAT is by nature a low cost program on a limited budget. The Army Space, Technology and Research Office (ASTRO) has provided monetary support to PANSAT as well as to numerous other academic efforts at NPS. [Ref. 5, p. 12]

Figure 1.2 graphically depicts many of the various requirements and constraints which influence the PANSAT program. Some of the more significant operational requirements include the following [Ref. 6, p. 18]:

- Communications transmitters and receivers capable of running Direct Sequence Spread Spectrum (DSSS) or straight binary phase shift keyed (BPSK) communications.
- 9842 bits per second (bps) data rate.
- Communications operations controlled by the Digital Control Subsystem (DCS) in AX.25 packet format.
- Error rate better than 10^{-5} bit error rate (BER).
- Single antenna for uplink and downlink.

A period of two years was chosen as an initial figure for desired satellite lifetime, providing ample time to conduct experiments and to utilize and prove the communications abilities of the satellite. Additionally, amateur radio operators will be afforded sufficient opportunity in that time frame to become familiar with, as well as to utilize, the capabilities of PANSAT. The requirements/constraints for low earth orbit, low cost, simple design, and low complexity were put in place to keep the PANSAT project within the scope of the capabilities of NPS. To maximize launch opportunities, PANSAT was designed and built as a small satellite, capable of being launched as either

MISSION

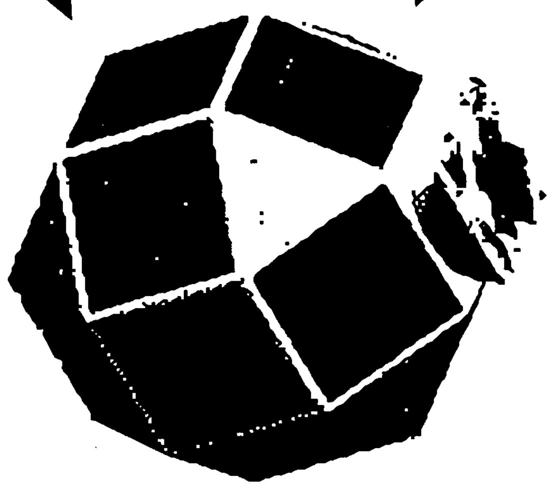
- 2-year life
- small satellite
- primary or secondary payload
- low cost
- simple design, low complexity
- military relevant frequency band
- store-and-forward comms.
- inclination ≥ 28.5° (for NPS coverage)
- low-earth orbit (radiation benign)

LAUNCH VEHICLE

- weight
- size
- mechanical interface
- safety requirements
- orbit
- launch vehicle ejection attitude
- integration
- testing
- ground operations
- documentation

FEDERAL COMMUNICATIONS REGULATIONS

- documentation
- amateur bandwidth
- launch field operations
- ITU notification



- digital communications satellite
- spread spectrum
- 150 lbs.
- 26-sided
- polyhedral-shaped
- omni-directional antennas
- spread spectrum
- 9.842 kbps

- 436.5 MHz
- 17 body mounted solar panels
- 1 LVI mounted solar panel
- no active attitude control
- no propulsion mechanism

Figure 1.2 Requirements and Constraints

a primary or a secondary payload. A minimum inclination of 28.5° was chosen in order to provide an adequate communications window for the ground station at NPS. Store-and-forward communications and a military relevant modulation scheme, i.e., spread spectrum, were incorporated into the design as well.

The requirements and constraints set forth by the selection of a launch vehicle impose strict limitations on the satellite design. Safety requirements are of profound importance, as are payload weight and overall dimensions. The mechanical interface between the satellite and the launch vehicle bears consideration, as do integration, testing, and ground operations. Orientation of the launch vehicle at ejection and the resulting orbit play an integral part in the satellite design, and must also be taken into consideration.

The documentation requirements set forth by NASA and the Federal Communications Commission (FCC) for space endeavors are extensive. The International Telecommunications Union (ITU) requires notification for frequency use. Additionally, launch field operations require extensive documentation and meticulous prior planning. Appendix A provides in-depth information concerning policy and documentation.

Planning for a Shuttle launch as a HH payload requires adherence to a specifically defined payload envelope. Maximum payload weight is 150 pounds, maximum diameter is 19.0 inches, and maximum height, or length, is 18.5 inches. Payload center of mass must lie within 0.5 inches of the centerline of the canister and cannot be greater than 10.25 inches above the separation plane of the Marman clamp interface [Ref. 7, p. 5]. To meet these parameters, PANSAT was designed as a 26-sided polyhedral-shaped, 150 lb. satellite. A center frequency of 436.5 MHz was chosen, with 2.5 MHz bandwidth, and spread spectrum modulation was selected for its application to military usage. Due to the desire to keep the satellite simple and on a low budget, neither an active attitude control

subsystem nor a propulsion mechanism are present on PANSAT. The satellite is designed to tumble along its flight path, so omni-directional antennas are installed to facilitate two-way communications and solar panels cover the majority of the exterior in order to provide for the spacecraft's power demands during periods of eclipse.

C. OBJECTIVES

The necessity for high returns on investments takes on added emphasis in light of ongoing reductions in defense spending. NPS's PANSAT endeavors to illustrate the application of digital communications technology as well as to fulfill the long-term needs concerning space education for military officers. PANSAT serves as an educational tool for project studies and thesis research for the officer students at NPS and will provide a quick reaction, low-cost, small satellite for store-and-forward communications using DSSS modulation. [Ref. 8, p. 1]

The objectives of PANSAT are:

- To provide an outstanding educational opportunity for the participating students at NPS through hands-on hardware development and system operation/management. Additionally, post-launch utilization of PANSAT is centered around educational endeavors.
- To provide proof of concept for digital store-and-forward communications, or packet radio, in the amateur frequency band by utilizing DSSS modulation. The store-and-forward bulletin board system will be available for message relay and telemetry.
- To provide for the acquisition of corporate knowledge and technical skills for the development of space flight experiments at NPS. [Ref. 2, pp. 111-114]

1. Educational Opportunities

The PANSAT project links the goals of education with the application of technology for the benefit of National Defense. The program supplies a variety of topics for graduate thesis research, providing exposure to real issues in the areas of design, development, integration, testing, and scheduling. Once in orbit, PANSAT will allow for

evaluation of the communications payload as well as for utilization as a space-based instructional laboratory for further educational benefit. The PANSAT program provides invaluable assistance to the Space Systems curricula in terms of educating students in the technical aspects of a space system. [Ref. 8, p. 1]

2. Proof-of-Concept

PANSAT will provide proof-of-concept for store-and-forward communications on a small satellite for students at NPS as well as for other users in the amateur radio community. Amateur packet radio is a communication method that allows for high-speed, error-free digital data exchange. The satellite will utilize a DSSS differentially encoded BPSK communications system and will be designed for use by amateur radio operators. PANSAT's store-and-forward communications system will allow HAM radio operators with the proper DSSS equipment to send and receive message traffic as the satellite passes overhead during one of its several short (6-10 minute) daily communications windows. [Ref. 6, pp. 4-5]

The amateur radio community has been closely involved with packet radio for over a decade and has been actively involved in the development and operation of satellites and the development of standards in communications protocols. PANSAT designers have worked closely with this group in order to learn from past experience as well as to benefit from their existing operations and design standards knowledge. [Ref. 9, pp. 1-2]

3. Design/Engineering Objectives

The purpose of the design process is to maximize individual component performance with respect to the associated design specifications. PANSAT is designed to fit inside a Shuttle Get-Away Special (GAS) canister as well as a number of other Expendable Launch Vehicles (ELV). As such, satellite weight and diameter are planned at 150 lbs. and 19 inches, respectively. Military and selected radiation tolerant

components will be utilized to demonstrate a low-cost design. The communications payload will operate in a half duplex, DSSS mode at a center frequency of 436.5 MHz with a data transmission rate of 9.842 kilobits per second (kbps). With the amateur radio community serving as the user base, PANSAT will operate from a low earth orbit (LEO) and employ spread spectrum packet radio communications.

Engineering objectives include all of the satellite's subsystems since the whole program is basically an experiment. PANSAT's subsystems, including structure, electrical power, communications, digital control, thermal control, guidance navigation and control, propulsion, and software, are defined in Chapter V. Facilitating the timely development and integration of PANSAT's various subsystems into a cohesive, well functioning satellite is an objective as well as a challenge facing the program personnel. [Ref. 5, p. 12]

D. FACILITIES

PANSAT constitutes the first full spacecraft development project at NPS. Prior experience was gained through space flight experiments flown on the Space Shuttle via the GAS program, like the Space Thermoacoustics Refrigerator (STAR), as well as through sounding rocket experiments [Ref. 10]. The STAR project marked the commencement of the SSAG infrastructure development. A precision fabrication facility was constructed to facilitate the building of STAR. Located in Bullard Hall, the lab is being used for the construction of PANSAT and will be available for future programs. The lab facilities and equipment are used not only for the PANSAT project, but also to support Space Systems Engineering courses such as AA3811: Space Systems Laboratory. An Engineering Qualification Model of the Navy FLTSATCOM satellite is on display at NPS and serves as a design tool, exposing students to design aspects of satellites. The model is located in Halligan Hall and is shown in Figure 1.3.

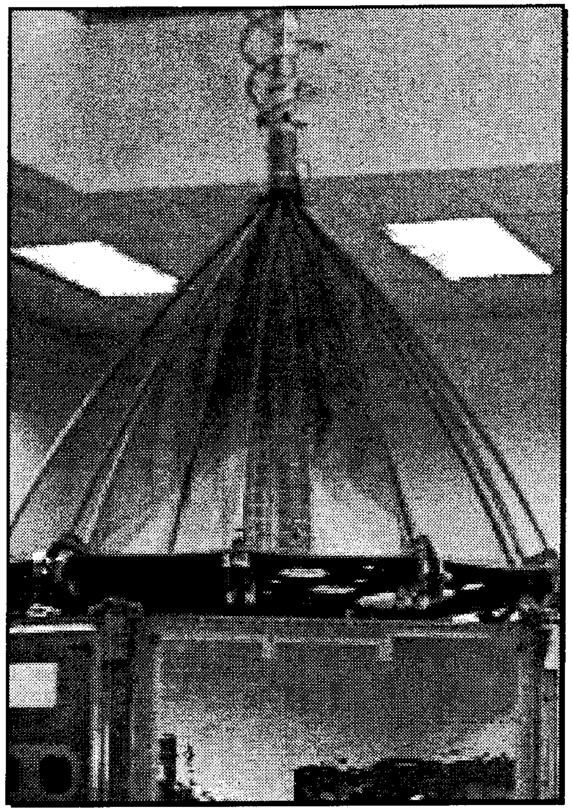


Figure 1.3 Navy FLTSATCOM Engineering Qualification Model at NPS [Ref. 11]

A capable infrastructure, consisting of tools, facilities, and support personnel, has been assembled in order to facilitate the successful completion of the PANSAT project. This includes the development of procedures and the acquisition of personnel with the requisite technical skills to perform design, analysis, and testing in support of PANSAT. The end product of the PANSAT project is not only the satellite itself, but also the accumulated laboratories and equipment that were built/acquired during the course of the project. The SSAG infrastructure comprises the equipment and manning to conduct hardware development for possible post-PANSAT spaceflight experiments in support of graduate education. [Ref. 11]

1. Design and Analysis Tools

Facilities, computer assets, engineers and support personnel are already in place at NPS to assist in the successful development of space flight experiments. Conceptual

design and engineering trade studies are aided by the use of packages such as the Structural Dynamics Research Corporation (SDRC) I-DEAS Master Series software (see Figure 1.4) for mechanical design and test and the full Cadence family of computer-aided-design (CAD), simulation, and analysis packages. Numerous software tools have been purchased specifically for spacecraft design, such as PC-ITAS for spacecraft thermal analysis and Orbital Workbench for orbital mechanics and satellite lifetime predictions. The following software companies and their respective products are just a small sample of the many resources available to support officer students, faculty, and staff at NPS [Ref. 11]:

- SDRC .... I-DEAS (Mechanical Design/Analysis)
- Cygnus Engineering .... Orbital Workbench
- Analytix Corp. .... PC ITAS (Thermal Analysis/Design)
- Cadence Design Systems, Inc. .... Cadence (Electronics Design Tools)

2. Hardware Development

Manufacturing and development facilities in place at NPS to support the PANSAT project, and ideally future programs, include a wide array of equipment. Machining capabilities and personnel expertise exist within the SSAG and provide short lead times for one-of-a-kind parts. One example of the outstanding equipment on hand is the Computerized Numeric Control (CNC) Vertical Milling Center, which is portrayed in Figure 1.5 and boasts the following features:

- high precision automated machining center,
- 0.0002 inch repeatability,
- 20 position automatic tool changer, and
- capability to perform complex shapes and contours.

Figure 1.4 CAD Workstation Using SDRC IDEAS for Solid Modeling [Ref. 11]

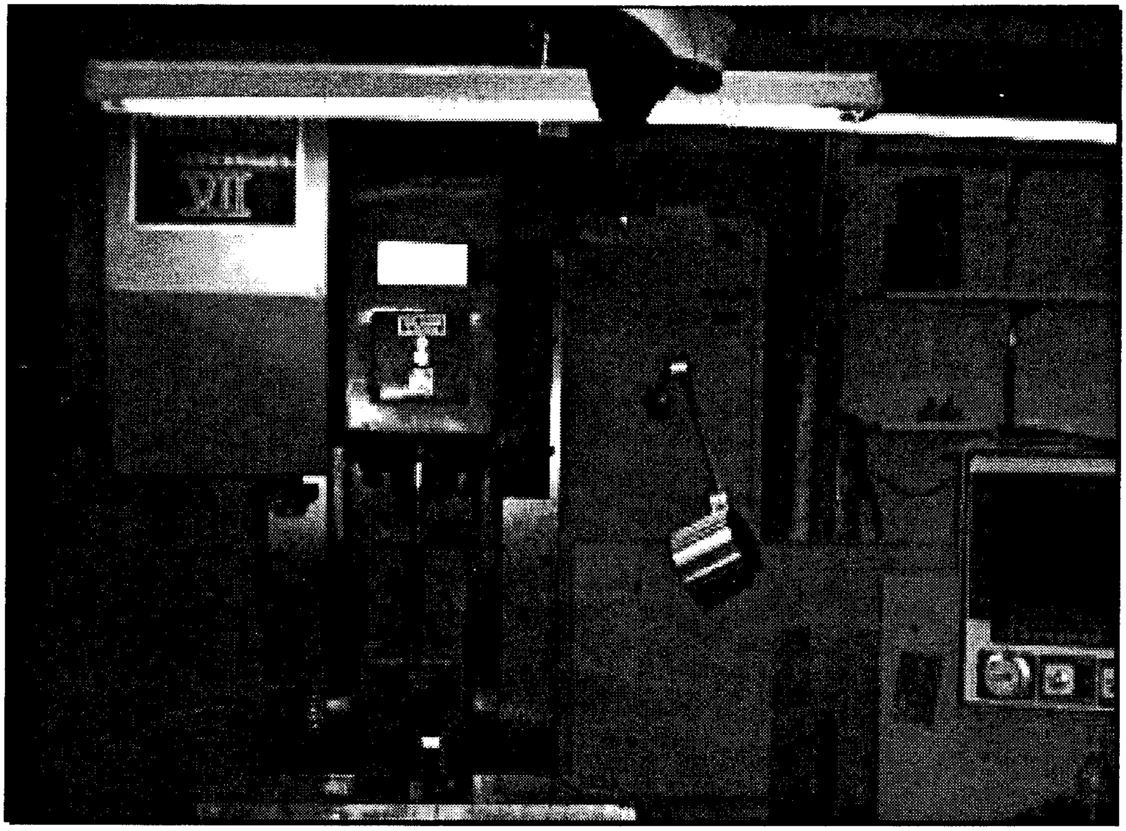


Figure 1.5 CNC Vertical Milling Center [Ref. 11]

Additionally, clean air facilities are in place to assist in the integration of instruments and space flight components. A laminar flow bench and a class 10,000 clean room, which is 12 feet long, 10 feet wide, and 8 feet high (see Figure 1.6), are maintained in Bullard Hall and are readily accessible for use by the PANSAT engineers. [Ref. 11]

3. Testing Equipment

Facilities are also in place for component and subsystem environmental testing. The major testing facilities currently operable include a 500 lb. shaker, a 3000 lb. shaker, and a one cubic foot thermal-vacuum chamber. The one cubic foot thermal-vacuum chamber is displayed in Figure 1.7 and possesses the following features [Ref. 11]:

- Temperature Control Range:........................ -73°C to +177°C
- Test Volume:.. 1 Cubic Foot
- Ultimate Vacuum: .... 7.5 x 10^{-8} torr

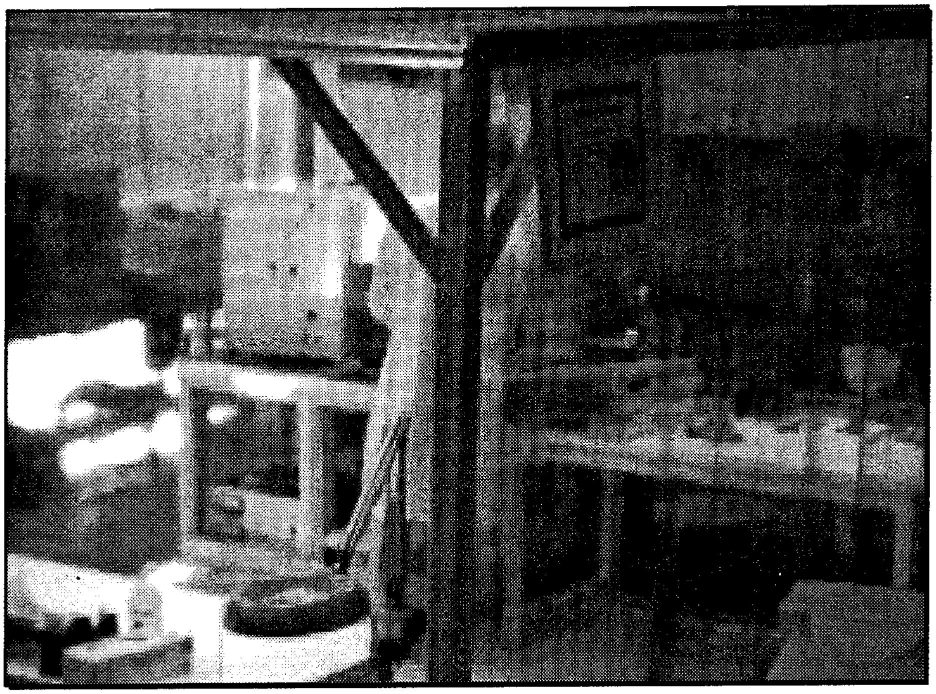


Figure 1.6 Clean Room Facility for Experiment Integration and Test [Ref. 11]

Additional testing equipment includes a larger version of the 1 cubic foot thermal-vacuum chamber (see Figure 1.8) and a Radio Frequency (RF) Shielded Enclosure (see Figure 1.9). The RF Shielded Enclosure is 10 feet long, 10 feet wide, and 8 feet high, while the large thermal-vacuum chamber contains a cylindrical-shaped test volume that is 3 feet long and 3 feet in diameter. The thermal-vacuum chamber is aligned horizontally and can be opened at one end. The vacuum system consists of a 9.6 kilowatt diffusion pump and a 1.5 HP mechanical roughing pump. Heating and cooling of the test volume are provided by gaseous or liquid nitrogen flow through copper coils within the chamber. The chamber is fitted with a 12 inch diameter viewing port and a multiple pin connector for in-situ (in the natural position) testing and boasts the following features [Ref. 12, p. 16]:

- Test Volume: .... 27 Cubic Feet
- Ultimate Vacuum: .... 10^{-8} torr

Critical laboratory facilities and equipment are powered by an uninterruptible power supply, which is depicted in Figure 1.10. In the event of a power failure during test or during integration, the uninterruptible power supply allows for the execution of a graceful shutdown period, thereby providing invaluable protection against the possibility of costly damage to space flight hardware. [Ref. 11]

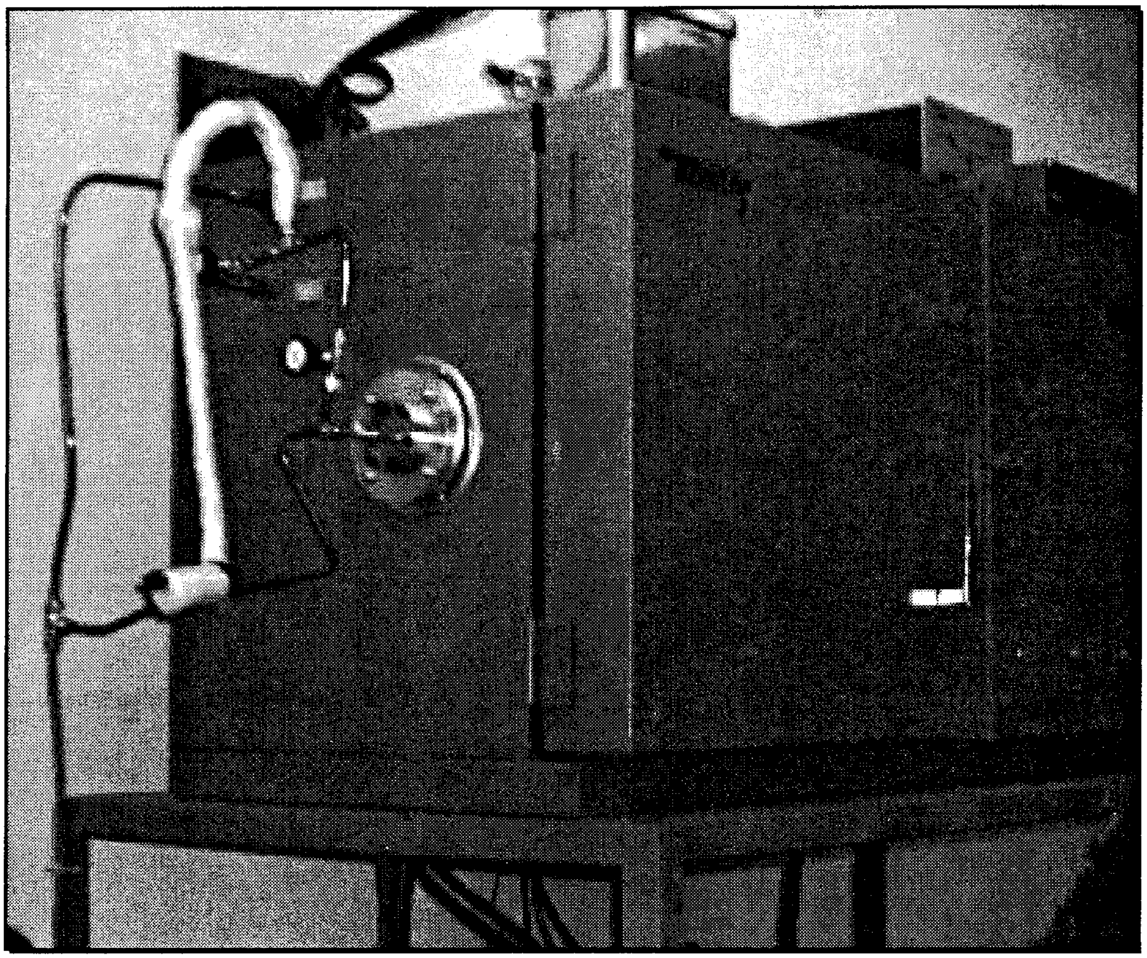


Figure 1.7 One Cubic Foot Thermal-Vacuum Chamber

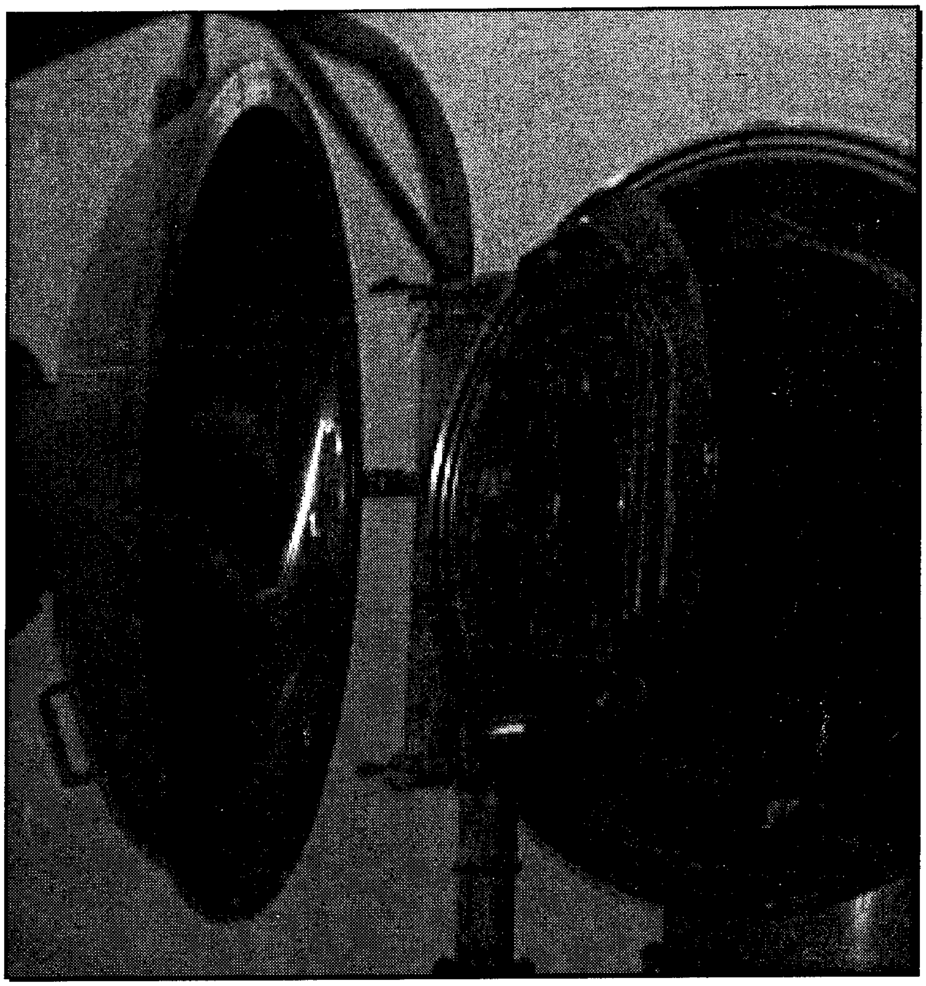


Figure 1.8 27 Cubic Foot Thermal-Vacuum Chamber [Ref. 11]

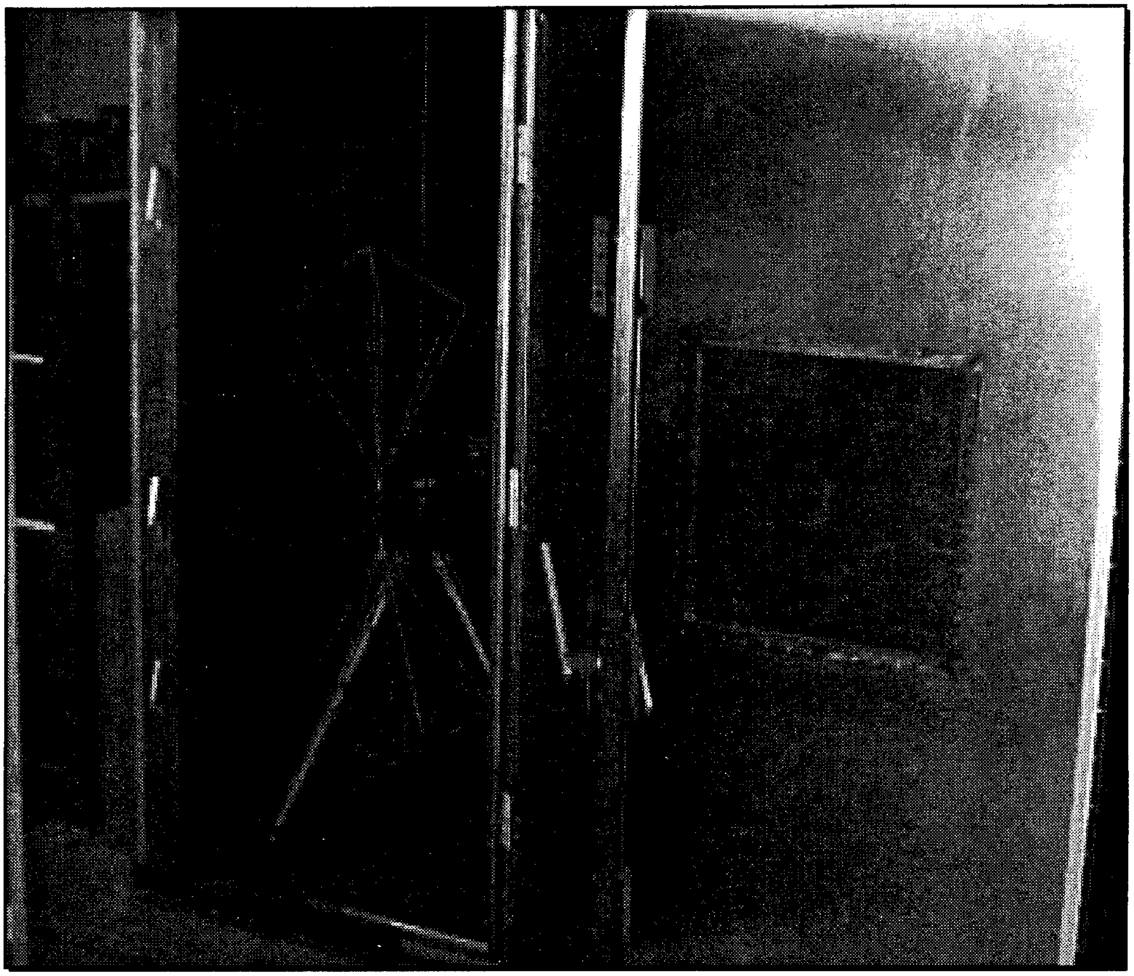


Figure 1.9 Radio Frequency Shielded Enclosure [Ref. 11]

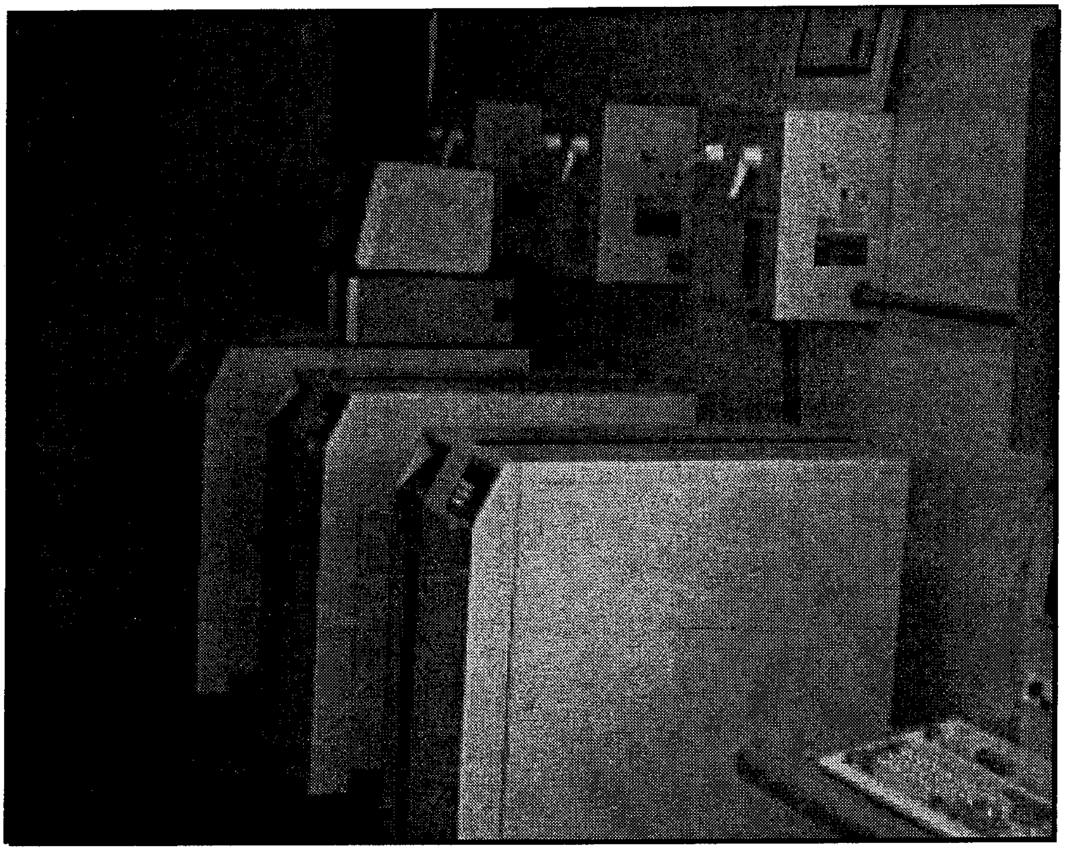


Figure 1.10 Uninterruptible Power Supply [Ref. 11]

E. MANAGEMENT AND ORGANIZATION

The personnel employed by the SSAG for the PANSAT project include two aerospace engineers, two electrical engineers, one electronics technician, one industrial engineer, and one master model maker. Responsibilities change to accommodate the needs of the program, so the information presented in Table 1.1 concerning the personnel involved with PANSAT has changed over the course of the project and is certainly subject to future alterations. The members of the engineering team have responsibilities and commitments external to the PANSAT project due to the fact that they are SSAG staff; the scheduler must keep this in mind when coordinating individual assignments.

Faculty Advisor	Title/Area of Expertise
Rudy Panholzer	SSAG Chairman; Principal Investigator (PI); PM
Michael Ross	Project Lead
Barry Leonard	System Design
Randy L. Borchardt	Communications Payload & Electrical Engineering (EE) Theses Coordinator
Dick Adler	Antenna Design
Terry Alfriend	Orbit and Attitude Dynamics
Bob Ashton	Electric Power
Doug Fouts	System Design; Point of Contact - Amateur Radio Users
Alan Kraus	Thermal Analysis
Sherif Michael	Solar Array
Sandi Scrivener	Structures
Fred Terman	Digital Control

SSAG Engineering Staff	Title/Job Description
Dan Sakoda	Systems Engineer; Mission Analysis/Design; S/C Configuration/Structure; S/C Operations/Analysis
David Rigmaiden	Communications Subsystem Coordination; Launch Field Operations
Ron Phelps	Electric Power Subsystem Coordination; Elect. Subsystems Interface Control Document (ICD)
Todd Morris	Systems Engineering Master Plan/Documentation; Systems Level Test Coordination; S/C Configuration/ Structure
Jim Horning	Digital Control Subsystem (DCS) Coordination; S/W Architecture, Design & Documentation; Subsystems S/W Design/Coding/Test
Glenn Harrell	Master Model Maker: Machining & Fabrication
Gian Duri	Coordination of Project Planning; Scheduling/Control; Functional Requirements Document

Table 1.1 PANSAT Personnel Roster

Team members provide the scheduler with information concerning their task/sub task progress; he in turn uses the inputs to maintain and update the master project schedule. [Ref. 13, p. 113]

PANSAT staffing has been a problem since program inception. Specifically, adequate manning is not in place/available to complete all of the required details necessary in the time prior to PANSAT's anticipated launch date. In fact, because the number of personnel employed by the project has been limited, the schedule, and thus the launch date, has experienced numerous delays/setbacks.

F. STUDENT INVOLVEMENT/SS4003

Officer students, primarily from the Space Systems curricula, represent the single greatest resource available to the PANSAT project. Opportunities for involvement exist in PANSAT-oriented directed study projects and in thesis research in Space Systems Engineering, Space Systems Operations, Electrical Engineering, Computer Engineering, Operations Analysis, and Computer Science, as well as in other curriculums. Courses (e.g., AA-4831 in the Space Systems Operations Curriculum) occasionally require PANSAT related projects, while a PANSAT-specific course, SS4003 "Spacecraft Design Studies," is offered on a quarterly basis. [Ref. 13, pp. 121-124]

Students interested in participating in the development of PANSAT and/or whose thesis pertains to some element of the PANSAT project may register for SS4003. In SS4003, systems-level aspects of the satellite design are considered, with the course following a group discussion/oral presentation format. The concurrent engineering design approach employed by this course simulates design meetings held in a typical industrial environment. The purpose of the class is to provide students with an overall appreciation for the project and to demonstrate how individual research efforts serve as essential pieces of the puzzle, contributing to the ongoing success of the program. NPS

faculty, SSAG engineering staff, and officer students attend and actively participate in the weekly class meetings. [Ref. 14, p. 1]

PANSAT became an international academic effort in May of 1995 when three German officer students arrived in Monterey as part of an exchange program. The trial program lasted for roughly three months; during this period the ambitious scholars made invaluable contributions in numerous engineering areas. At that time, the exchange was one-way, meaning that U. S. students were not yet traveling abroad like their German counterparts. The goal is to eventually expand the program for the benefit of both countries' research endeavors. The major impediment to the successful implementation of the plan is the lack of German-speaking officer students in the pertinent curricula at NPS, so unfortunately the two-way aspect of this conceivably rewarding program has yet to be realized.

G. EXTERNAL RESOURCES/INTERFACING

1. Space Test Program (STP)

The Department of Defense (DOD) Space Test Program (STP) is a DOD-wide activity that is under the executive management of the Air Force. The DOD STP is chartered and funded to provide space flight opportunities for DOD research experiments which are not authorized their own means of space flight. The program has flown approximately 100 missions carrying over 300 experiments since it began in July of 1966, and continues to provide services to the "DOD research and development community through its funding and management of spacecraft fabrication, test, experiment integration, launch vehicle integration, flight support, orbital operation, and finally, transmittal of data to the experimenters for analysis and dissemination." A list of typical STP responsibilities can be found in Table 1.2. This is just a typical listing and is not a definitive list of what will be provided to PANSAT. [Ref. 15]

• Perform preliminary planning to define mission concept and opportunity
• Select compatible experiment candidates for a mission
• Establish schedule for mission
• Define mission orbital parameters
• Establish spacecraft requirements
• Acquire, integrate, launch, and operate the space system
• Provide integration and spaceflight management
• Provide orbital support for mission
• Provide post flight ephemeris, attitude, and flight history of spacecraft
• Provide agencies with flight data for 1 year

Table 1.2 STP Responsibilities [Ref. 15, p. 3-1]

2. Federal Communications Commission (FCC)

Users desiring to use frequencies in the amateur radio band must notify the Federal Communications Commission (FCC). This is accomplished by executing the appropriate FCC documentation requirements outlined in section 97 of The FCC Rule Book, or Code of Federal Regulations (CFR). When drafting FCC notifications, a normal delay time of five to six months from initial filing to publication of notification should be anticipated. Additionally, the most current edition of the applicable references should be consulted, since federal rules and requirements involving this constantly evolving field occur on a continuous basis. [Ref. 16, pp. 82-89]

The FCC performs spectrum management, with satellite communications (i.e. PANSAT) being included in their realm of responsibility. NPS is currently pursuing licensing of PANSAT as an amateur satellite operating within the scope of the amateur satellite community. Appendix A covers policy and documentation requirements in

detail and lists and describes the FCC documents that are required as part of the licensing process.

3. Detachment 2

Detachment 2 (Det 2), located at Onizuka Air Force Base in Sunnyvale, California, provides a complete, centralized, space safety program, as well as vital on-orbit information and support. The Det 2 Test Support Complex (TSC) is equipped with "leading-edge, high-reliability, space-test telemetry, tracking, and command and control equipment for real-time spacecraft control." Their computer facilities and architecture allow for interfaces for telemetry applications, Time Space Position Information (TSPI) analysis, and packetized telemetry, and enable Det 2 to supply customers with an integrated data package in the customer's required format. The PANSAT program will be requesting orbital information, in the form of telemetry data, from Det 2. [Ref. 17]

Request for program support is initiated by contacting the Det 2 customer service office at (310) 363-2504/DSN 833-2504. A liaison is established between the customer and a single point-of-contact at Det 2, a representative who provides guidance and assistance with all of the various requirements and documentation. Det 2 uses standard test range Universal Documentation System (UDS) forms, in conjunction with a cost-efficient automated tool to aid in the paperless generation and electronic transfer of UDS documents. [Ref. 17]

4. Support Activities

The design, development, construction, launching, and support of a satellite is obviously a very complex undertaking. The end product is the culmination of a massive effort by a multitude of personnel performing specific tasks related to their areas of expertise. Each piece of the puzzle must be carefully assembled in the quest to attain a finished product. PANSAT requires support from a variety of sources; as an example of the plethora of inputs required to build and operate a small satellite, Table 1.3 describes

the support activities utilized in the construction of the Amateur Radio Satellite Corporation (AMSAT) Orbiting Satellite Carrying Amateur Radio (OSCAR) satellite program [Ref. 16, pp. 4-7 and Ref. 18, p. 13-1]:

•Design of flight hardware	•Launch operations
•Construction of flight hardware	•Travel to launch site
•Testing of flight hardware	•Ship satellite to launch site
•Finished drafting	•Connect satellite to launch vehicle
•Interfacing with launch agency	•Final checks
•Provide documentation related to satellite-rocket interface	•Technical studies focusing on future spacecraft design
•Provide safety related documentation	•Create launch information nets
•Identifying and procuring future launches	•Miscellaneous needs
•Construction management	•Insurance
•Parts procurement	•Licensing
•Arrange overall timetable and deadlines	•Procurement contracts
•Monitor progress of all subgroups.	•Corporation papers
•Allocating available resources (financial and human)	•Coordination with international AMSAT affiliates
•Locating volunteers with special expertise	•Construction of test equipment and special test facilities
•Provide user information	•Financial management
•"Orbit" magazine production	•Overseeing record keeping
•Amateur Satellite Report newsletter production	•Auditing as required
•Weekly AMSAT nets and information broadcasts via satellite	•Estimating future needs and cash-flow situation.
•Respond to requests for information	•Maintain historical records
•Produce information programs (slide shows, videotapes)	•Telemetry
•Facilitating magazine article and book production	•General
•Supporting educational programs	•Create command station network
•Fund raising	

Table 1.3 Representative Satellite Program Support Activities [Ref. 16, pp. 4-7]

This list is just a partial list and represents only some of the myriad of elements that must be taken into consideration in the production of a satellite, no matter how small and simple it may seem. Amateur space pursuits carry fewer bureaucratic requirements than do similar commercial or military ventures, so the list of supporting activities for PANSAT promises to be much more extensive.

II. HISTORY

One of the original objectives of PANSAT was to provide a small, space-based platform to support future experiments. Due to PANSAT's petite stature, any and all experiments will have to satisfy strict power, weight, and volume requirements. Two such experiments that were proposed were an annealing, or recovery, of radiation damaged solar cells experiment and a ferroelectric memory experiment. Unfortunately, neither experiment ever got past the planning stage. Space (volume) constraints, power limitations, and lack of hardware readiness, as well as vague interface requirements on the part of the experiments, all combined to bring about their demise. The LVI underwent a few modifications during the design process, including the squaring off of the edges and the addition of solar cells. These changes result in a reduction in shadowing of adjacent solar cells and a corresponding increase in satellite power production.

A. ANNEALING EXPERIMENT

The major experiment proposed for PANSAT was the on-orbit testing of annealing of radiation damaged solar cells. When exposed to extremely high temperatures, solar cells exhibit recovery from radiation damage. A process called forward biased current annealing can be used to reduce the temperatures required for annealing. Considerable cost savings for prospective space systems may be realized if the lifetime of solar cells can be extended by the annealing process. Candidate solar cell materials included silicon, gallium arsenide, and indium phosphide. The payload was to be an autonomous Motorola 68701-based experiment with 64K of static Random Access Memory (RAM) and 16K of Read-Only Memory (ROM). Fifteen cells were to be subjected to testing with a sixteenth cell to be used as a sun sensor. [Ref. 1 and Ref. 2, p. 113]

B. FERROELECTRIC MEMORY EXPERIMENT

The second proposed experiment for flight aboard PANSAT was the testing of ferroelectric memory. Ferroelectric technology is attractive for space applications because it is inherently radiation tolerant, non-volatile, and high in density. Major concerns facing ferroelectric memory devices are retention and endurance. If the issues of retention and endurance can be alleviated, ferroelectric memory devices have the potential to evolve into the unequivocal choice for space-borne solid state memory. [Ref. 2, pp. 113-114]

C. LVI MODIFICATIONS

The adapter envelope requirements set the adapter dimensions so as to ensure proper interfacing between the adapter and the clamping mechanism. Since the maximum adapter dimension was set at 9.375 inches at the separation plane and the initial LVI design was circular, the original LVI extended horizontally beyond the edges of the bottom panel of the satellite. The resulting overlapping of the lower angled solar panels would lead to shadowing when the sun is in a position directly below (facing) the adapter. Reduced power output from the solar array would result from this configuration, and since PANSAT possesses no attitude control, this undesirable orientation could occur at any time. The associated power loss may or may not have been absorbable by PANSAT's power margin, so a means to preclude shadowing was deemed desirable. Figure 2.1 depicts PANSAT from the bottom, i.e., with the LVI facing the observer. Figure 2.1 also displays the payload envelope diameter (labeled ø), which is 19.0 inches, and the area of one of the solar cells (0.92 cm^2) on one of the body mounted solar panels. [Ref. 3, pp. 15-17]

The detrimental effects that would be brought about by the use of a conical shaped LVI led to the design of a tapered, shadow-minimizing LVI. This design utilizes the same profile as the circular option, but with one major change. To eliminate

shadowing, the circular edges of the LVI were cut vertically in order to make the outline of the LVI square so as to match the bottom panel of PANSAT. This modification removes the material that was causing the shadowing of the lower arrays when PANSAT orientation placed the LVI directly between the sun and the satellite. [Ref. 3, p. 19]

An AA4831 (Spacecraft Structures II) class project undertaken at NPS in the spring of 1994 recommended adding solar cells to the LVI. Gallium arsenide (GaAs) solar cells were chosen over silicon cells due to the increased efficiency provided by GaAs cells and the reduced area presented by the LVI as compared to the 17 solar panels. The addition of 22 GaAs cells to the LVI aids the power generation capability of the Electrical Power Subsystem (EPS), which in turn supplements the satellite power budget.

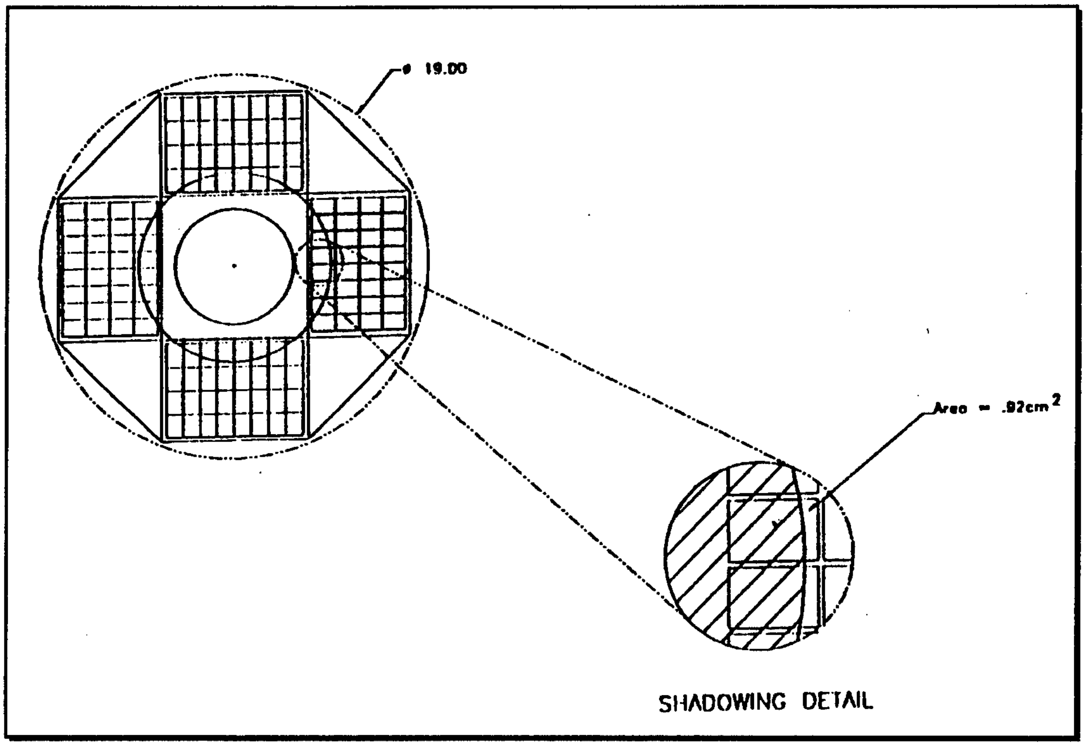


Figure 2.1. Circular LVI Shadowing [Ref. 3, p. 16]

III. USER OPERATIONS INTRODUCTION

A. COMMUNICATIONS

After initialization, PANSAT will conduct normal operations by remaining in a receive-only mode at all times, waiting for a request-to-connect command from a ground station. After acknowledging the user, PANSAT will begin the information-relay phase, during which the user will be able to access a bulletin board service. The bulletin board offers services that allow the user to send and receive mail that is stored on-board PANSAT, upload and download files, and read spacecraft telemetry. The use of sophisticated protocols will allow users to interleave their activities with those of PANSAT, thereby enabling multiple users to communicate simultaneously with the satellite. When the information-relay is complete, the user will log out and the station will send a request-to-disconnect command to end the session. [Ref. 1, pp. 1-5]

Information transfer is effected when the user interfaces with an application software which, in turn, communicates with the spacecraft via another software solution that manages and controls the communications link. Minimal interaction is required by the user because all protocol commands will be performed automatically by software. Packet transfer, or the relay of frames of information, will be transparent to the user, with the protocol closely resembling (in fact derived from) the computer networking protocol X.25. PANSAT will implement AX.25, which is a standard link-layer protocol used by amateur radio operators. Packet store-and-forward services will be provided by application software which will operate in a layer above the AX.25 link layer. [Ref. 2, pp. 1-2]

A point-to-point communications path for users over PANSAT's single physical communications channel is made possible by the use of AX.25, which embeds each message with a source and a destination address. In order to receive their messages, users will have to connect to the spacecraft. Users will have to accomplish message retrieval

on a fairly routine basis, as PANSAT will only store messages until they are down-linked or until they are considered undeliverable and consequently purged from memory as a part of system administration. Thus, the PANSAT mode of message handling functions in much the same way as a terrestrial bulletin board system, with notable differences being that PANSAT will operate from orbit and no physical connection (i.e., medium) will be necessary. One foreseeable problem with this scenario is that PANSAT's mail storage is very limited in capacity, which will necessitate the removal of old, unread messages when lack of available storage dictates. The time frame for the removal of old messages will be dynamic and will be a function of the storage space available. Storage space will be provided by a redundant pair of four megabyte (MB) memory modules. After initialization and proof of successful operation, these two modules could be tasked to perform separately, thereby effectively doubling the storage space, with potentially only a very small reduction in reliability. [Ref. 2, p. 2]

The uploading and downloading of files, or file transfer, occurs in a manner similar to the orbiting mailbox concept. The difference, however, is that as a file transfer facility, PANSAT will allow the transfer of any format of file, including text and binary. Files may contain executable programs, graphics, images, encoded voice, and possibly even a word-processed file. Of course, due to storage limitations, there will still be limitations regarding file size, number of files, and length of time each file remains on PANSAT. [Ref. 1, p. 5]

A popular item that amateur users like to retrieve from orbiting satellites is spacecraft telemetry. PANSAT will allow users access to current spacecraft telemetry and will transmit the telemetry in an encoded form in order to minimize the number of bits of information exchanged with the ground station. Connection time will be further minimized by the fact that users will perform the necessary decoding after disconnecting from PANSAT. Decoding information and a program for personal computers to conduct this task will be made available by NPS. [Ref. 1, p. 5]

Assuming a minimum usable elevation of 10° and a 28.5° inclination, low earth orbit (LEO) insertion via the shuttle, NPS would have a maximum communications window of approximately 8 minutes with PANSAT during each of its approximately three passes per day. Using the STS-86 anticipated inclination of 51.6°, the communications window would remain at about 8 minutes but the number of passes would increase to roughly four per day. In addition to an increase in the number of passes per day, higher inclinations also equate to longer orbital lifetimes [Ref. 2, p. 1 and Ref. 3, pp. 93-98].

B. USER GROUND STATION OPERATIONS

Potential users should be able to access PANSAT by using a personal computer, a Terminal Node Controller (TNC), radio transmission and receiving equipment, special spread spectrum hardware and PANSAT-specific user-interface software to match PANSAT's spread spectrum capability. The SSAG is developing a design for an inexpensive, generic Ham kit to provide an amateur radio operator with all of the necessary hardware and software required for the demodulation of the spread spectrum signal and communication with PANSAT. [Ref. 3, pp. 40-42 and Ref. 4, p. 4]

The use of digital technology in the form of the PARAMAX PA-100 chip in the Communications subsystem incurs numerous advantages. Digital technology uses less area on the satellite, reduces satellite power requirements, provides flexible data rates, and is programmable. Additionally, the increased flexibility inherent in digital design allows for the future addition of multiple spreading codes and ease of adaptation to other systems. The fact that the amateur radio kit was made more affordable by the application of digital technology is a key factor when considering the implications of monetary outlay on the part of the amateur radio operator. Another aspect of the proposed Ham kit is that to increase acceptance by the amateur radio community, the kit should be adaptable for possible use with other satellites and systems. This concern is satisfied by

the employment of digital technology. To facilitate communications with PANSAT, an amateur radio operator must utilize a ground station that is nearly identical to the SSAG's command ground station. The software that amateur radio operators are provided via the Ham kit will differ from the command ground station software in areas such as command and control capability and security passwords, which, for obvious reasons, will only be available to the command station. [Ref. 3, pp. 42-43]

IV. DIRECT SEQUENCE SPREAD SPECTRUM OVERVIEW

Spread spectrum modulation provides the advantages of low probability-of-intercept (LPI), low probability-of-detection (LPD), resistance to jamming and low probability-of-interference (to and from other users in the band) [Ref. 1, p. 2]. The use of spread spectrum techniques offers several additional significant advantages, especially in military applications. Although not all of the following are applicable to PANSAT, additional advantages of spread spectrum include [Ref. 2, pp. 8-9]:

- Code division multiple access (CDMA) capability, which enables selective addressing of communications and multiple user access to a single communications channel;
- Low probability of recognition (LPR) signal, which enables the effective "hiding" of the signal in the noise, in the interference, or in other communications;
- High resolution ranging, which is determined by the rate of the system. Very high range resolutions are available in spread systems, such as the Global Positioning System (GPS);
- Interference rejection, which is intentionally putting the signal level around the ambient noise level, while still being able to successfully extract the signal.

In the past, the use of spread spectrum techniques has been limited mostly to military applications. By their nature, spread spectrum systems utilize more bandwidth than is required for the information being transmitted. This inherent inefficiency has kept spread spectrum from widespread use in the private sector where the bandwidth allocations are limited. Recently the paying public has expressed an increased interest in spread spectrum modulation and its intrinsic advantages, particularly concerning low-power, high-density personal communication devices. [Ref. 3. Appendix A]

The PANSAT team initially attempted to complete the necessary documentation to utilize frequencies in the military band. Due to the multitude of systems and signals already in residence and the extended time period required for approval, the Naval Electromagnetic Spectrum Center (NAVEMSCEN) suggested the use of the amateur

band. Thus, the decision was made to pursue a HAM frequency through the American Radio Relay League (ARRL), which greatly simplified the requisition process while still meeting all of the original PANSAT design/engineering goals. [Ref. 2, p. 10]

With Direct Sequence Spread Spectrum (DSSS), the modulated carrier is expanded to the extent that it occupies a bandwidth that is much greater than the information bandwidth of the signal. This is accomplished by multiplying the information signal by a pseudo-noise (PN) spreading sequence which has a bit rate that is significantly greater than the information data rate. The resulting process spreads the signal energy over a wider portion of the frequency spectrum. The same PN sequence must then be used by the receiver to despread the signal. [Ref. 3, App. A]

The amount that the signal is spread is determined by the ratio of the bit rate of the spreading sequence divided by the data rate of the information signal. This ratio is also referred to as the processing gain, which is denoted by Gp. The bandwidth of the spread signal is the product of the bandwidth of the unspread signal and the processing gain. Each bit of the PN sequence is commonly referred to as a chip, so the bit rate of the sequence is correspondingly called the chip rate. For PANSAT, the chip rate is 1.25 Mcps and the data rate of the digital message is 9.842 kbps. This results in a processing gain of 127, which is equivalent to 21 decibels (dB). [Ref. 3, App. A]

As its name implies, a pseudo-noise sequence is a deterministic sequence that appears to be random. The most common PN sequence is a maximal length sequence, or M-sequence. The sequence is generated by using a binary linear feedback shift register. The PANSAT Communications subsystem utilizes a seven stage M-sequence generator, with taps at 7 and 1, which results in a maximum sequence length of 127. This number is derived by using the formula $2^n - 1$, with n=7 (2^7-1=128-1=127). [Ref. 3, App. A]

V. GENERAL PANSAT DESCRIPTION

A. PHYSICAL DESCRIPTION

PANSAT's 26-sided, polyhedral shaped exterior will be composed of 18 solar panels, a base-plate, or LVI, for attachment to the launch vehicle, four dipole antennas mounted on four triangular-shaped surfaces, and four additional triangular-shaped surfaces. The eight triangular surfaces will be coated for passive thermal control. Since PANSAT will tumble along its flight path, this configuration provides the most uniform distribution of solar energy on the solar arrays. The spacecraft will weigh less than 150 lbs. and will be 18.62 inches in diameter and 19.5 inches in height, which will provide the necessary internal space for the assorted subsystems while keeping it within the strict payload envelope imposed by the STS SSCP program. Figure 5.1 shows the PANSAT configuration.

B. SUBSYSTEMS

1. Structure Subsystem

PANSAT is approximately spherical in shape with a diameter of 18.62 inches, incorporating modularity for ease of fabrication and component installation. The .0625 in. thick frame panels provide stiffness for the structure and a 7.125 in. x 7.125 in. surface for mounting the solar arrays. The LVI (see Figure 5.2) will be constructed of titanium while the rest of the structure employs aluminum (6061-T6), which features a high strength-to-weight ratio as well as good machining properties.

The LVI, or adapter fitting, attaches the satellite structure to the ejection mechanism of the GAS canister. The adapter must be designed with two distinct requirements in mind [Ref. 2, pp. 4-6]:

- design must be robust enough to survive worst case scenarios, i.e., worst case launch loading at maximum satellite mass during shuttle launch, during the

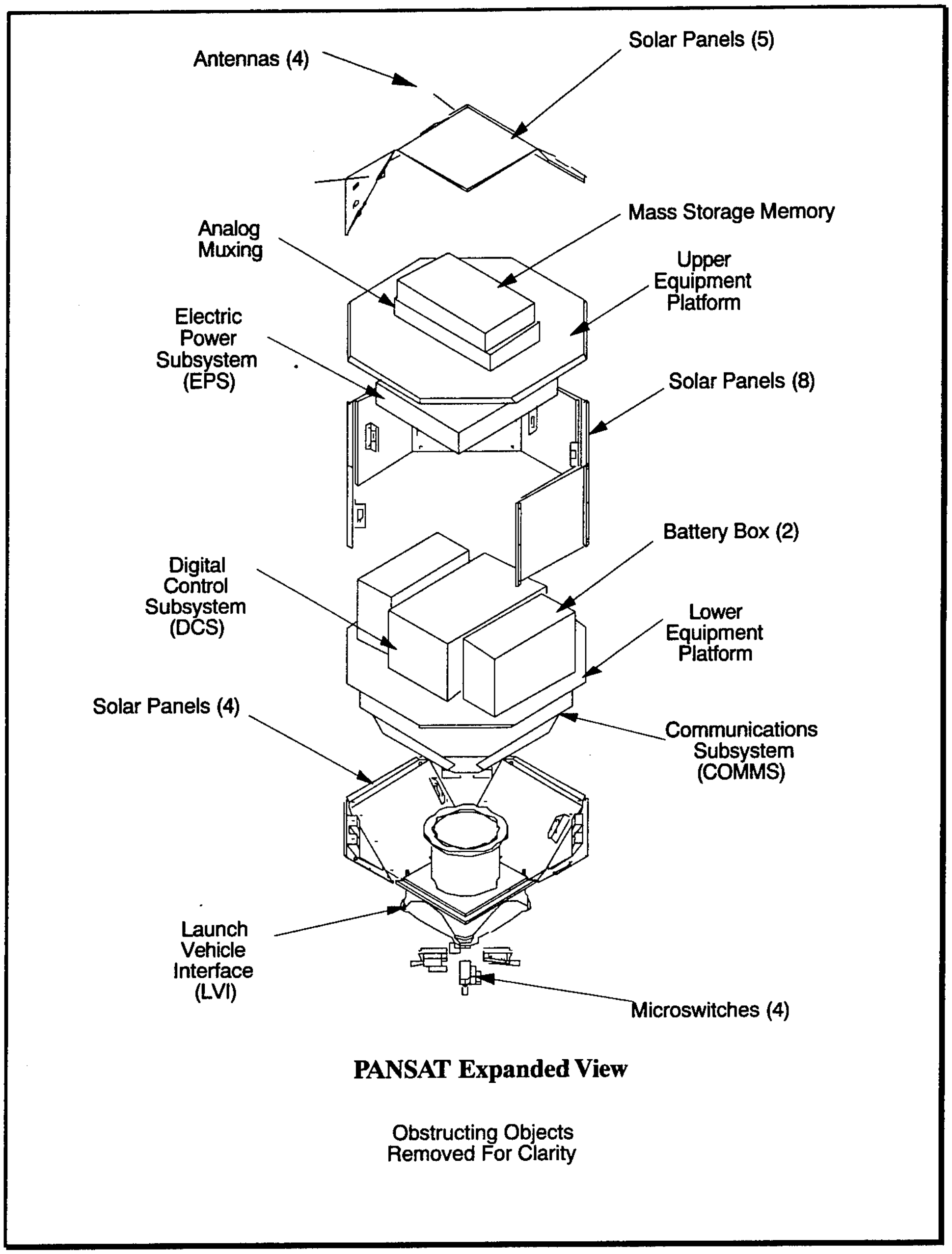


Figure 5.1 PANSAT Configuration [Ref. 1]

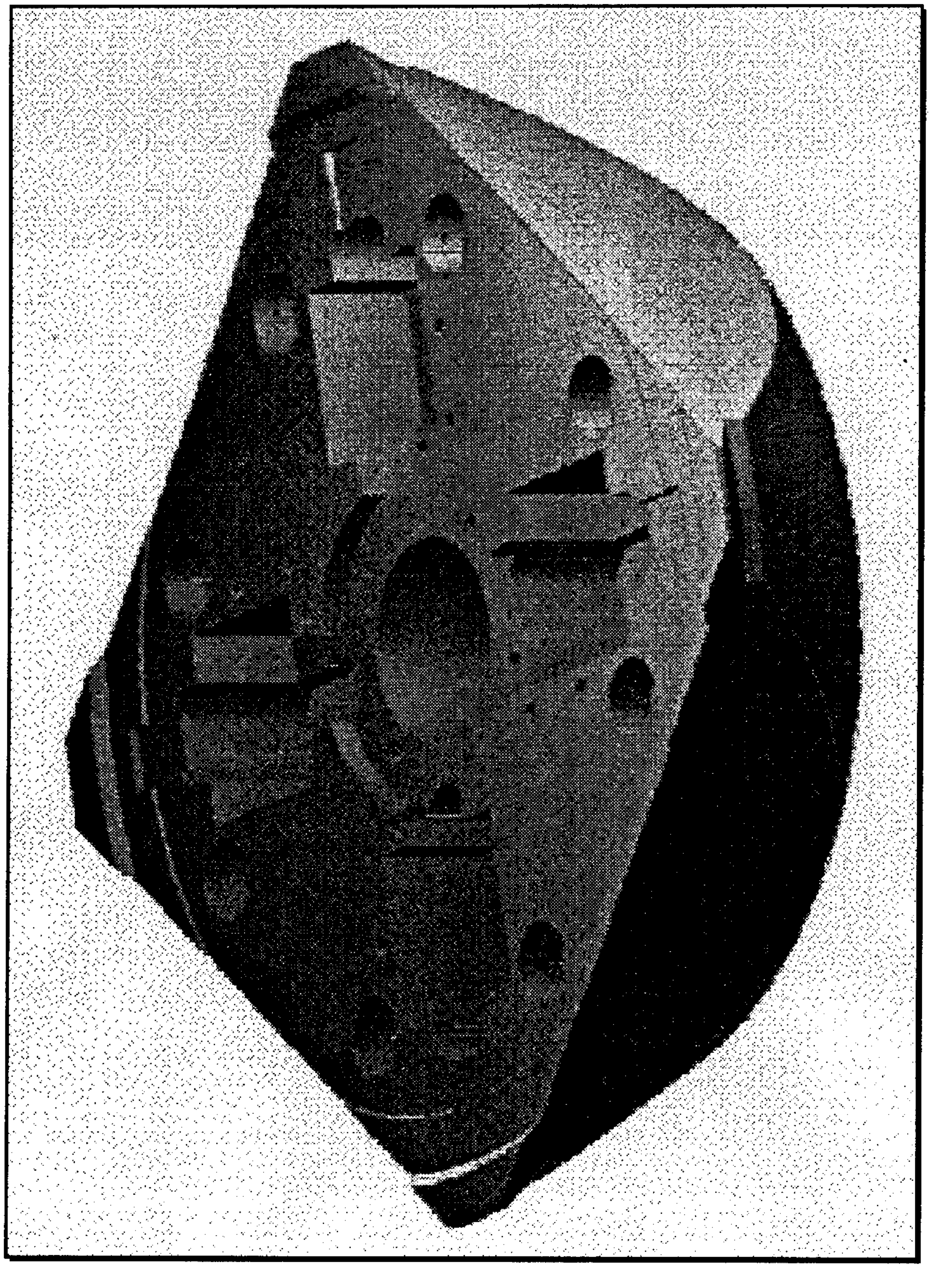


Figure 5.2 LVI [Ref. 1]

ejection sequence from the GAS canister, and during possible landing in the shuttle in the event of a mission abort, and

- design must be of sufficient stiffness so as to not allow the frequency of the LVI to couple with the natural frequency of the shuttle.

The internal satellite structure is composed of upper and lower equipment platforms, two end blocks, and a cylindrical shell, and is depicted in Figure 5.3. The .0625 in. thick cylinder is mounted directly to and supports the lower equipment plate. As the main load-bearing structure, the cylinder transfers loads from the spacecraft to the LVI. The lower equipment plate is .30 in. thick and is designed to carry up to 85 lbs. of equipment, which represents 57% of total allowable spacecraft weight, while the upper equipment plate is in excess of .25 in. thick and is capable of supporting in excess of 37.5 lbs. of equipment. The equipment plates are thicker than structurally needed but this eases the fastening of subsystems as well as aids the satellite in the attainment of the targeted weight. The discrepancies between upper and lower equipment plate thicknesses and load bearing capacities are due to the added stiffness that the support cylinder provides to the lower plate. An aluminum mock-up of the entire structure was built to physically demonstrate allowable subsystem envelopes and to provide a model for vibration testing. The experimentation culminated in verification of finite element analysis (FEA) through modal testing. [Ref. 3, pp. 9-10]

A finite element analysis of the proposed structure was conducted using SDRC I-DEAS interactive software. Results revealed that PANSAT easily met a positive margin-of-safety for loads of ± 9g's translational acceleration in theX, Y, (and X+Y) directions, and ± 15g's in the Z direction. Prescribed loads for Shuttle GAS launches are listed in the GAS Safety Manual for GAS payloads. [Ref. 4, p. 5]

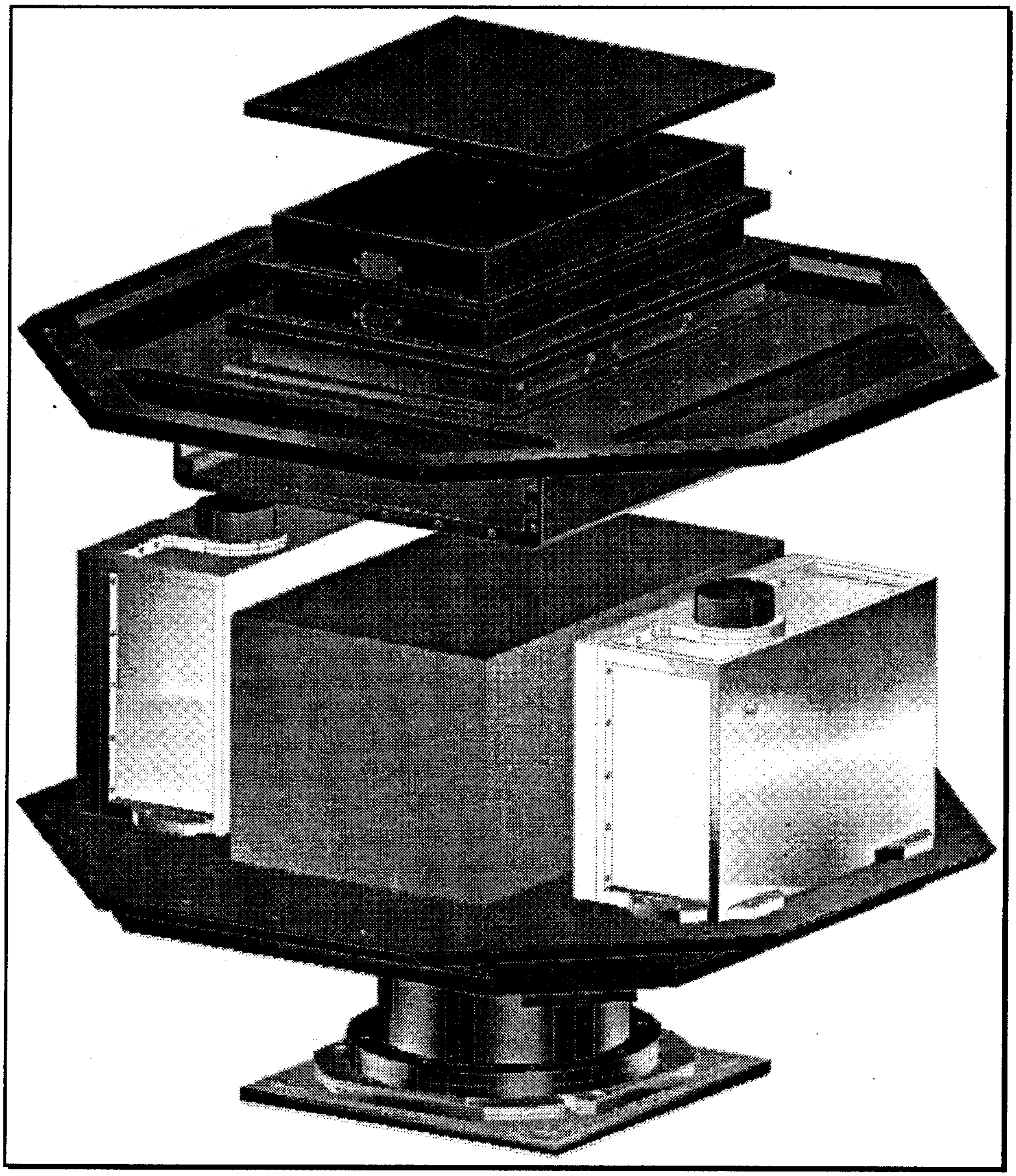


Figure 5.3 Internal Configuration [Ref. 1]

2. Electrical Power Subsystem (EPS)

The Electrical Power Subsystem (EPS), which is designed to provide efficient power distribution to all satellite subsystems, consists of three major components:

- 18 solar panels for primary power conversion (17 silicon and one gallium-arsenide),
- two nickel-cadmium (NiCd) batteries for power during eclipse, and
- power regulation/conditioning and telemetry circuitry, current sensing circuits and voltage multiplexing circuitry.

The EPS relies on the main spacecraft processor for the activation of relays and for the determination of charge levels and charge cycles. Power will be distributed via an unregulated power bus, at 12 V ± 3 V, to the Digital Control Subsystem (DCS) and to the Communication Subsystem (COMM). Figure 5.4 shows the EPS circuit board housing. [Ref. 4, p. 3]

Due to the length of time between payload integration and ejection from the Shuttle, PANSAT's nickel-cadmium batteries may be depleted beyond operational capability at launch. Ideally, PANSAT ejection will occur immediately after the Shuttle emerges from the eclipse portion of its orbit. In this manner, the spacecraft would be subjected to sunlight for the maximum amount of time at beginning-of-life (BOL), allowing battery charging. When the spacecraft enters eclipse during the early stages of the mission, a low-power mode of operation will be enabled until one of the batteries reaches sufficient capacity. [Ref. 4, p. 3]

The purpose of PANSAT's silicon solar panels is to provide power to the electrical bus during periods of sunlight. Silicon cells were chosen due to their low cost and adequate power efficiency. A minimum efficiency of 14.5 % at Air Mass Zero (AM0) and 28°C was deemed necessary based on the initial power budget estimates. Each silicon cell is 1.92 cm x 4.00 cm. Each of the 17 solar panels will consist of 32 series-connected cells, redundantly wired. Each solar panel encompasses an area of

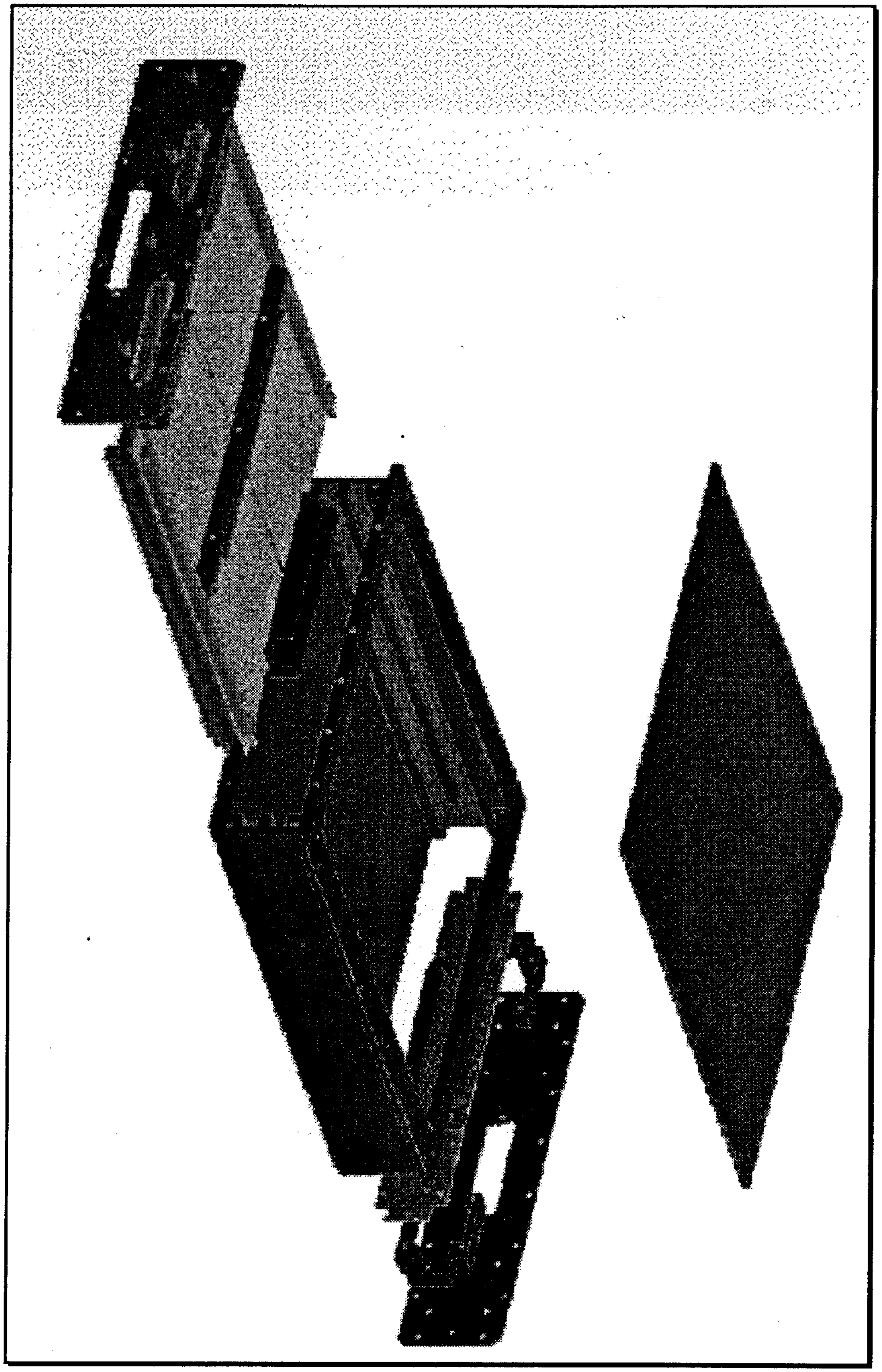


Figure 5.4 EPS Circuit Board Housing [Ref. 1]

approximately 256 square centimeters. The solar panels were fabricated by Spectrolab, Inc. of Sylmar, California, and utilize the K6700 silicon cell with back-surface field and back-surface reflector (BSFR). [Ref. 4, p. 3] A Gallium Arsenide (GaAs) solar panel (see Figure 5.5) is used on the bottom, external surface of the LVI and will be built by Satellite Power Corporation. The LVI panel provides a smaller area available than the other 17 body panels and utilizes GaAs cells due to their greater efficiency and higher voltage output. All solar panels will have their outputs clamped at, or limited to, 16 volts.

The two NiCd batteries are responsible for providing power when PANSAT is in eclipse. Optimally, the batteries will be capable of maintaining bus voltage at 12 volts. Additionally, during all phases of operations, the NiCd batteries are tasked with voltage regulation. Voltage sensors monitor the solar panel voltages and battery voltages, while thermal sensors keep track of solar panel, battery, and electronics housing temperatures. [Ref. 5, pp. 39-41]

3. Communications Subsystem (COMM)

The COMM subsystem is simplex, or half-duplex, which means it incorporates a single channel for both up-link and down-link, with the up-link and down-link functions being mutually exclusive (i.e., they do not occur at the same time). Data rate will be 9.842 kilobits per second (kbps). The spacecraft will operate at a center frequency of 436.5 MHz in the amateur radio 70-cm band and will occupy a bandwidth of 2.5 MHz. The *Code of Federal Regulations* (CFR) places some restrictions on amateur radio spread spectrum, but at the same time amateur radio involvement provides a large user base. [Ref. 4, p. 2]

In compliance with the CFR, the pseudo-noise (PN) code sequence is implemented by using a 7-bit shift register with taps at 7 and 1. The PN code is combined with the data stream at a rate of 1 sequence length per bit of information, or 127 chips per bit. The spread signal is then modulated using binary-phase-shift-keying (BPSK) and up-converted to the transmitted carrier. The transmitter aboard PANSAT is

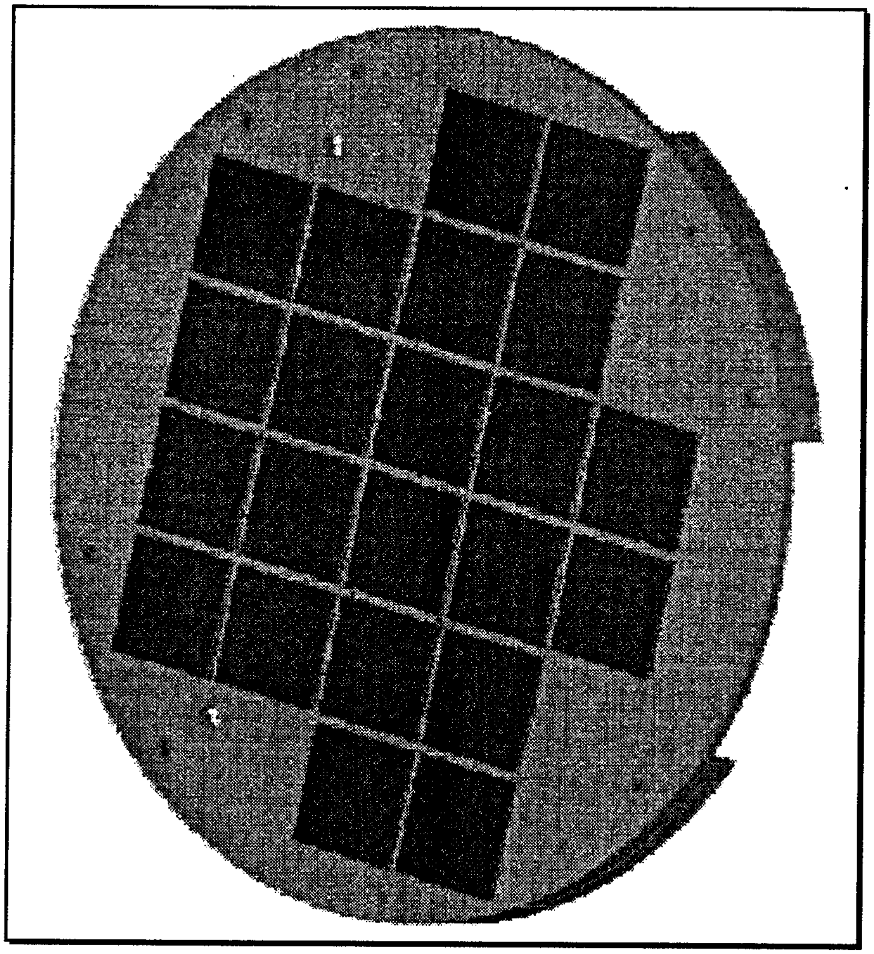


Figure 5.5 GaAs Panel [Ref. 1]

capable of varying the output power so as to use only the minimum amount required for successful reception. [Ref. 4, p. 2]

The spread spectrum receiver onboard PANSAT provides signal detection, tracking, and demodulation for recovery of the digital data stream. The data stream is passed to a serial communication controller (SCC) for de-packetizing and error-checking by means of a cyclical redundancy check (CRC). The recovered data is then delivered to the spacecraft DCS for processing. The receiver is capable of receiving a carrier of at least -120 dBm signal strength. [Ref. 4, p. 2]

The COMM system has been developed around a digital design that became available through Application Specific Integrated Circuit (ASIC) technology, the PARAMAX PA-100. The PA-100 provides for much of the functionality of spread spectrum, on just a single chip, which replaces several full circuit boards of analog components. The chip incorporates the following features [Ref. 5, pp. 24-25]:

- De-spreading, demodulation, Costas Loop carrier recovery, PN code detection and tracking, data synchronization, and AGC all on one chip.
- Data rate up to 64 Megabits per second (Mbps) (PANSAT rate remains 9.842 kbps).
- Chipping rate up to 32 Mcps (PANSAT rate is 1.25 MHz).
- Multiple modulation modes including BPSK and Quadrature Phase Shift Keying (QPSK).
- Spread or clear communications modes.
- Maximum 48 dB processing gain.
- Low bit error rate.
- Simple 8-bit controller interface with the DCS.

The PA-100 consists of DSSS transmitters and receivers with some level of redundancy, although there are still some single-points of failure present in the system. Each transmitter and receiver is capable of switching from wide-band spread spectrum

modulation to narrow-band BPSK modulation, which allows for emergency operation and the down-linking of a narrow band telemetry beacon. BPSK is important for users who are in the early stages of setting up their ground stations and/or for users whose equipment is not spread spectrum capable. [Ref. 4, p. 3]

To facilitate two-way communications, four antennas will be attached to four of the triangular surface panels on the exterior of the structure. The four dipole antennas will be placed in a tangential turnstile configuration and will provide omni-directional coverage. Radiated power from the antennas is expected to be two watts or less. [Ref. 6, p. 1]

4. Digital Control Subsystem (DCS)

The primary functions of the Digital Control Subsystem (DCS), which is also referred to as the Command and Data Handling (C&DH) Subsystem, are to:

- provide control and monitoring of the EPS,
- provide control and operation of the COMM payload,
- gather, organize, and store telemetry data,
- perform management of onboard non-volatile memory, and
- provide control of message traffic. [Ref. 4, p. 3]

DCS design has undergone numerous iterations by officer students at NPS, with the fulfillment of the functional requirements serving as a guide. The DCS design implements both a multi-tasking operating system to provide store-and-forward communications and "pair and spare" technology to provide redundancy for space operations. The current DCS design consists of dual, mutually exclusive control boards to provide the desired redundancy, each run by an Intel M80C186XL microprocessor. The M80C186XL microprocessor was selected because of its proven architecture, radiation tolerance, low power consumption, availability of development tools, and capability of supporting a multi-tasking environment. The DCS control boards

communicate with redundant four-megabyte mass storage units and analog multiplexing (AMux) modules for temperature.

The DCS is composed of modules, one of which is the Spacecraft Test Probe Interface (STPI). The STPI provides for a ground support alternate communication link and is an input/output (I/O) handler. In that role, the STPI provides an interface between an RS-232 connector and the other modules of the DCS. Communications with the satellite can be accomplished without having to use a radio frequency link. [Ref. 7, p. 3]

5. Thermal Control Subsystem (TCS)

A spacecraft's thermal control subsystem (TCS) regulates the internal temperatures and maintains them within a temperature range that is in accord with the spacecraft equipment's operating temperatures. For PANSAT, these internal temperature limits were determined to be 4°F for cold case and 53°F for hot case [Ref.8]. Due to PANSAT's simple design, only a passive TCS will be utilized. There are no heating or cooling elements nor are there any moving parts. Geometry and material composition will be used to control radiative and conductive heat paths, thereby providing temperature regulation. [Ref. 7, p. 3]

6. Guidance Navigation and Control (GNC)

PANSAT lacks an attitude control subsystem, which leads to a decrease in performance as well as a considerable reduction in complexity. Fortunately, however, the absence of an attitude control subsystem also brings about a considerable reduction in development, in reliability concerns, and in safety issues. The telemetry, tracking, and control (TT&C) functions will be distributed between and handled by the COMM and DCS subsystems. [Ref. 3, p. 1]

7. Propulsion

PANSAT possesses no propulsion subsystem and is designed to "tumble" along its orbital path once it is released from the launch vehicle. Satellite orbit will be

determined by the launch vehicle at ejection and the satellite will not be capable of any orbital maneuvers. Thus, the release point in orbit takes on added importance and will play a large part in the usable service life of the satellite. [Ref. 6, p. iii].

8. Software

Software is an important aspect of the PANSAT program, encompassing three major design goals [Ref. 9, p. 3]:

- maximum use of existing software with reliable functionality,
- requirement that software modifications, as well as new software modules, can be uploaded to and exercised on PANSAT subsequent to launch, and
- compatibility of software developed at NPS with Amateur Radio software and standards presently in use.

Pictorial flow diagrams to aid in the design process were developed using the All CLEAR program from the company All CLEAR. The software development process is also simplified by the use of Computer Aided Software Engineering (CASE) tools, which provide software diagramming techniques and strict methods of software module interface design. CASE tools aid in the visualization of software design and in the presentation of software designs to persons not intimately familiar with the software development process. The PANSAT software design group utilizes Evergreen's Easy CASE Plus. [Ref. 9, p. 3]

In order to maintain adherence to strict timing requirements, certain low-level functions will be coded in 80186 assembly language. Intel's ApBuilder, which is a software development tool for microprocessor initialization and configuration set-up, was used to assist in the generation of initialization code for each peripheral embedded within the microprocessor. However, C was used to implement the majority of the software because of the familiarity of team members with the language, the availability of tools, and the ease of integration with other third party software operating systems. [Ref. 9, p. 3]

PANSAT's software environment possesses two powerful and important features, one of which is its ability to perform software modifications. Additionally, the software environment is capable of uploading new software modules after launch. Since errors are not anticipated in the original launch software and since it is impossible to predict every single operational scenario, this feature is a realistic and intelligent approach to combat potential software shortcomings. [Ref. 9, p. 5]

VI. TESTING

The subsystems of the satellite may be individually tested prior to integration, thereby simplifying the process of failure detection and correction. However, before the testing phase of the satellite as a unit can commence, the systems have to be integrated. Systems integration is a complicated process that is best achieved through extensive interaction between all of the involved engineers/parties from the beginning of the project. Meticulous planning and coordination during design and development are also essential to the systems integration effort.

A. HITCHHIKER TEST REQUIREMENTS

Structural integrity verification, to include both testing and analysis, must be conducted on all payloads desiring to qualify for the HH Program. The Space Shuttle environment during launch, orbit, and reentry drives the requirements. A system level ground test plan will be used to assist PANSAT in satisfying the HH requirements as well as in preparing the satellite for operation. [Ref. 1, pp. 7-8]

1. Strength Requirements

To preclude damage to the Space Shuttle and/or injury to the crew, HH payloads must display the ability to withstand all Shuttle environments without experiencing structural failure. Experiments may attain qualification by successfully completing structural testing to 1.25 times the limit loads and by analysis showing a positive margin of safety of 1.4 times the limit loads for all of the modes of ultimate failure. Design limit load factors are ± 11g's in the x, y, and z axes, as well as angular accelerations of ± 85 radians per square second (rads/sec^2) in the x, y, and z axes. Experiments may also gain qualification by analysis with positive margins of safety of 2.0 for material yield and 2.6 for all of the modes of ultimate failure. [Ref. 1, p. 8]

2. Natural Frequency Verification

The lowest allowable natural frequency for a HH experiment is 35 Hz. A verification test is not required if analysis predicts that the lowest natural frequency is greater than 100 Hz. A verification test is required if the predicted natural frequency is less than 100 Hz or if no analysis has been conducted. If the lowest natural frequency is less than 50 Hz, testing may be required in order to verify the mode frequencies and shapes. [Ref. 1, p. 8]

3. Random Vibration

Every experiment must undergo a random vibration test to qualify for the Shuttle vibro-acoustic environment. The Generalized Shuttle Component Random Vibration is used as the basis for the test levels. Testing in each of the three orthogonal axes is required to be of at least one minute in duration. [Ref. 1, p. 8]

4. Electrical Responsibilities

Although the HH program does not require the experimenter to conduct electromagnetic interference (EMI) testing, payloads must follow the EMI control requirements of the Shuttle Interface Control Document, ICD-2-19001, Sections 7.2 and 10.7. The HH Project Office performs conducted and radiated susceptibility tests and transient tests on all experiments to confirm compliance with EMI requirements. [Ref. 1, p. 9]

5. Thermal Responsibilities

To maintain the payload temperature within prescribed parameters, heaters, thermostats, blankets, and coatings are used. Thermal analysis, design data, surface coating and insulation descriptions, and a thermal math model must be provided for all payloads requesting manifestation, but the HH Program does not require any actual testing in regard to thermal aspects. [Ref. 1, p. 9]

B. SYSTEM LEVEL TEST FLOW

A series of environmental and functional tests will simulate the sequence of environments and operations that PANSAT will be subjected to during flight. The two types of functional tests are the Comprehensive System Test (CST) and the Integrated System Test (IST). The CST is a comprehensive, end-to-end test of all functions of a payload while the IST is more limited in scope and duration and is intended to identify any change in system performance resulting from a specific environmental test. Environmental tests include an electromagnetic interference (EMI)/ electromagnetic compatibility (EMC) test, a sine sweep vibration test, a random vibration test, and a thermal-vacuum test. The System Level Test Flow for PANSAT is shown in Figure 6.1. [Ref. 1, pp. 9-11]

In the event of a test failure anywhere in the sequence, the test sequence will cease and a detailed failure analysis will be conducted. The satellite will be returned to the test sequence at the point of failure if the failure does not overstress the system and falls into one of three categories:

- failure caused by test equipment,
- failure caused by set-up, or
- failure requiring only minor corrective action.

Major re-work or redesign of a satellite component will require a functional retest of the failed subsystem and a restart of the test sequence. Determination of what constitutes a minor corrective action as opposed to a major corrective action can only take place on a case by case basis and will be predicated by such factors as:

- number of components re-worked,
- environmental test history of the replaced component(s), and
- functional importance or influence of the failed component(s). [Ref. 1, pp. 11-12]

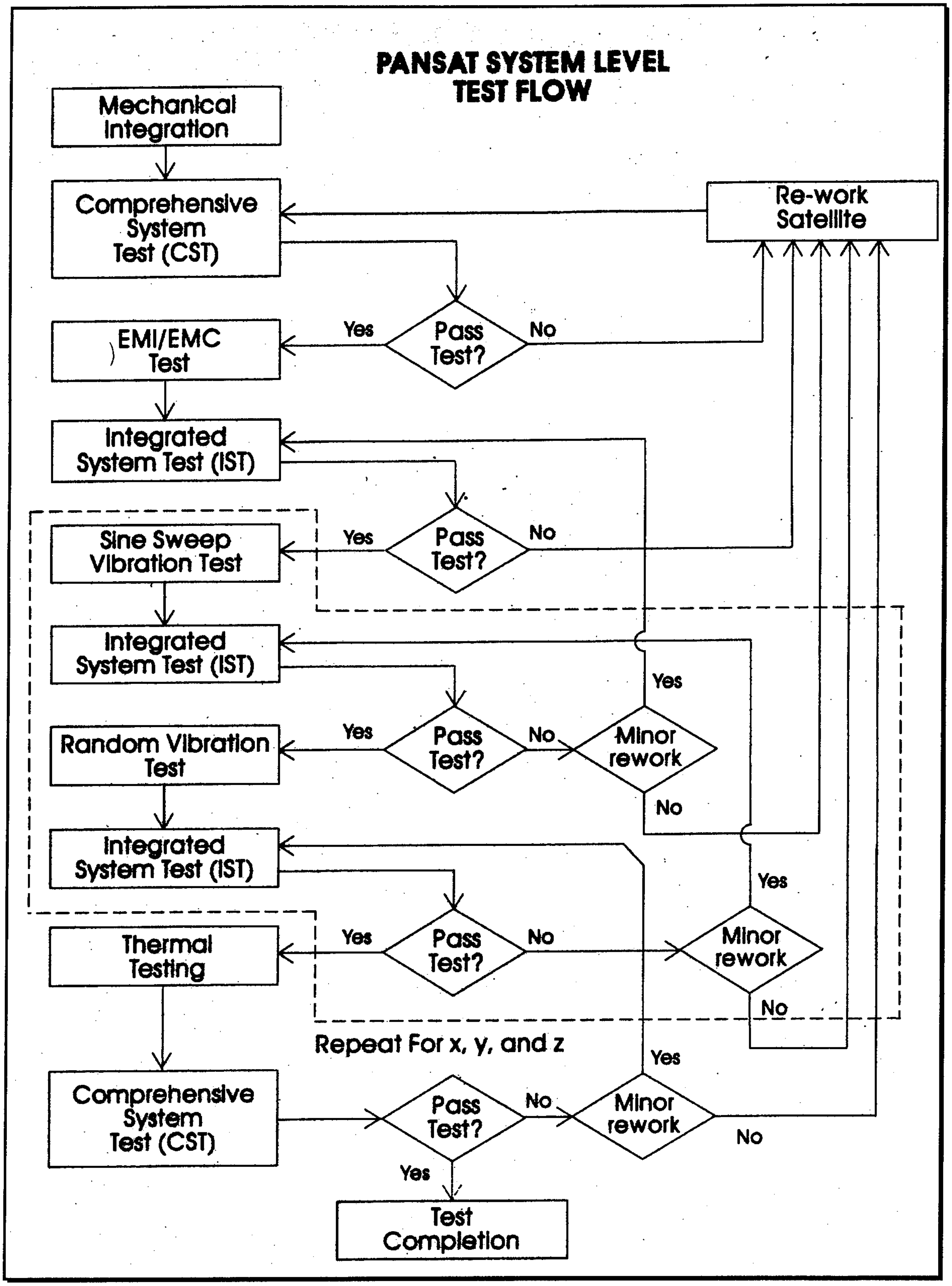


Figure 6.1 PANSAT System Level Test Flow [Ref. 1, p. 11]

System test data will be retained in a data library. A test traveler, or test script, will be used to document the test flow, and will document items such as the personnel conducting the tests, the applicable dates, and the data files. A qualification report will be written at the conclusion of the testing, verifying completion of all of the tests as well as the accuracy of the test data. [Ref. 1, p. 17]

C. SYSTEM LEVEL TEST SPECIFICATIONS

1. Functionality Testing

The CST will be an end-to-end test conducted through radio frequency (RF) link only. Tests will be conducted on PANSAT to include events such as launch vehicle separation, start-up, and normal operations. Test results will be deemed successful if the performance requirements for all of the variables tested are fulfilled. Test equipment and performance requirements for the CST are still to be determined (TBD). [Ref. 1, p. 12]

The IST will be a functional test of limited scope and duration in comparison to the CST. Communication with PANSAT will be accomplished through an RS-232 connection. Like the CST, test results will be considered successful if the performance requirements for all of the variables tested are met. Test equipment and performance requirements for the IST are TBD. The test may be conducted in differing locations, dependent upon the accompanying environmental test. As an example, subsequent to a vibration test, PANSAT could conceivably go through the IST while still physically attached to the electrodynamic shaker used for the vibration test. [Ref. 1, p. 12]

2. Vibration Testing

The sine sweep vibration test is used to identify the lowest natural frequency of the integrated structure. A low-level sinusoidal excitation sweeps through a prescribed frequency range with a prescribed frequency resolution. The response is measured by accelerometers attached to the device under test. The test data gives a relation between structure response and frequency and shows the frequency of greatest response, which is

the natural frequency of the system. Test equipment will include a 3000 pound-force electrodynamic shaker and closed-loop vibration control software running on an HP 9000 workstation. [Ref. 1, p. 13]

The random vibration test is an environmental test used to verify capacity to withstand the launch vehicle vibro-acoustic environment. A random test incorporates concurrent excitations over a prescribed frequency range, with variable excitation amplitudes and fixed time-averaged energy levels. The test is administered in the x, y, and z axes for a duration of three minutes. The test levels are determined by the HH Project and are shown in Figure 6.2. Test equipment includes a 3000 pound force electrodynamic shaker and closed-loop vibration control software run on an HP 9000 workstation. [Ref. 1, pp. 13-14]

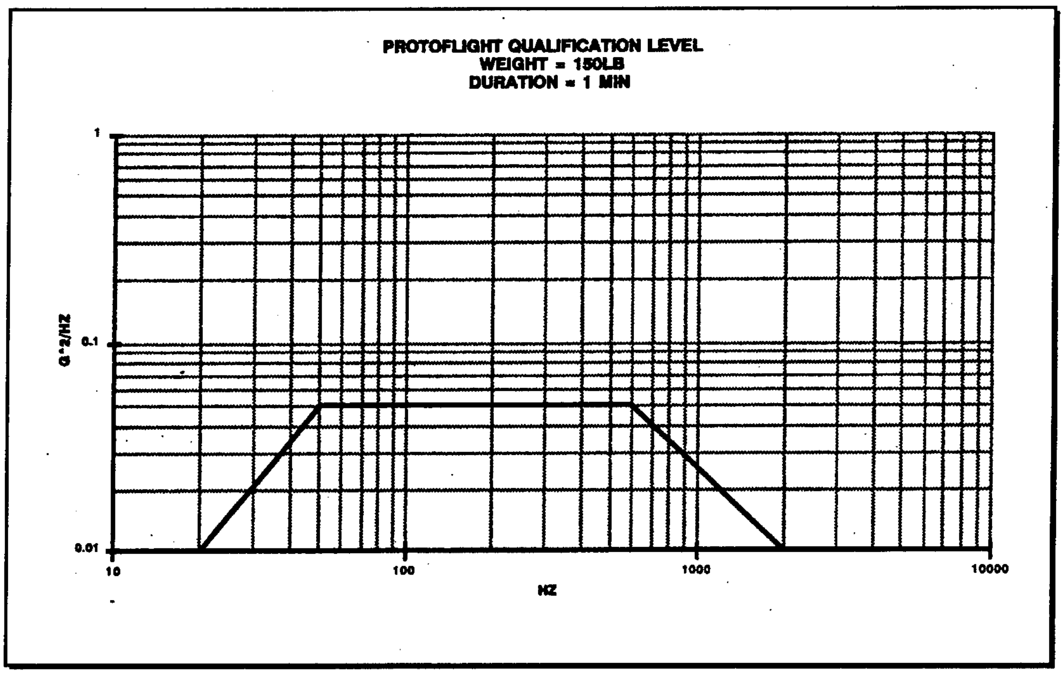


Figure 6.2 Random Vibration Test Levels [Ref. 1, p. 13]

3. Thermal-vacuum Testing

The thermal-vacuum test is an environmental simulation of the temperature and vacuum conditions that PANSAT will encounter on orbit. The degree of difficulty

presented by the test conditions provides an important indicator regarding spacecraft workmanship. PANSAT will be powered up and subjected to a total of two thermal cycles, with IST functional tests taking place at ambient temperature and at the hot and cold extremes. [Ref. 1, p. 14]

Thermal cycle temperature extremes have been determined by going 10° past the estimated operating temperatures for the most sensitive components. Thus, the extreme values for temperature are -10°C and +50°C. As shown in Figure 6.3, the first thermal cycle entails a four hour soak at each extreme of temperature, while the second cycle calls for 30 minutes dwell time at each temperature limit. The test shall be controlled so that the temperature change is limited to an average of 1°C per minute. At all times during the thermal cycles, the test chamber must be maintained at or below 1×10^{-4} torr and PANSAT's electrical systems must remain powered up. The thermal cycle may be interrupted only after the completion of a full cycle, unless emergency conditions dictate otherwise. After an interruption, the thermal cycle may be resumed for cumulative effect, i.e., it does not require resumption of testing from the beginning of the first cycle. Detailed information concerning the Space Simulator, or 27 cubic foot thermal vacuum chamber, along with the other facilities used in the PANSAT program, can be found in Chapter I. [Ref. 1, pp. 15-16]

D. DEVELOPMENTAL TESTING

Satellite developmental testing is the purpose of the System Integrated Development (SID) test, which is basically a functional test of prototype hardware. A combination of prototype hardware, laboratory equipment, and LabView graphical programming software are used in the conduct of the test, which serves two purposes [Ref. 2, p. 1]:

- to validate the design and exercise hardware control of electronic subsystems, and
- to develop control algorithms to control the sequence of hardware states of various subsystems to provide functionality and operation.

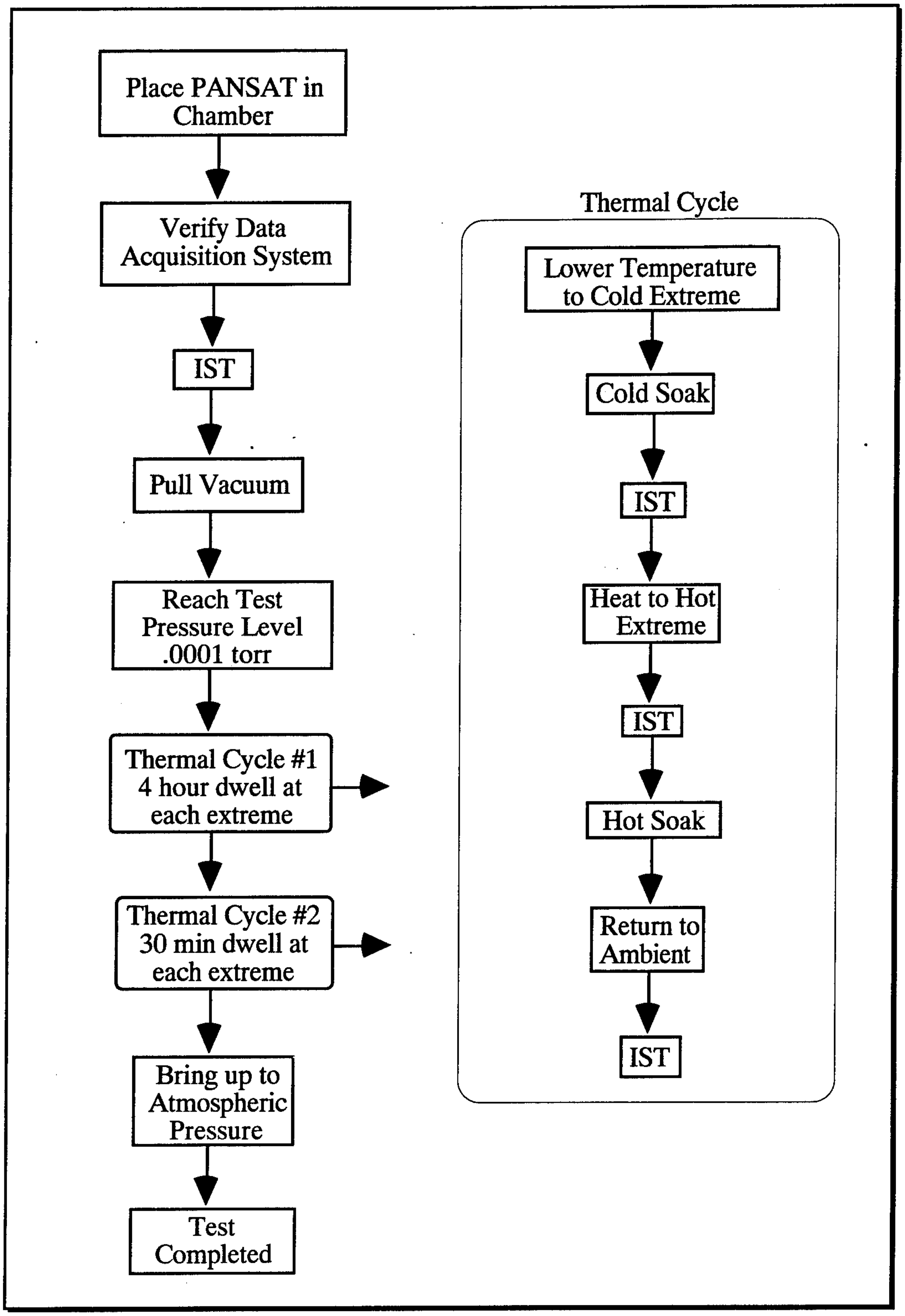


Figure 6.3 Thermal Vacuum Testing [Ref. 1, p.15]

SID testing will be broken down into two phases. During the first phase, functional validation of the subsystem design and prototype hardware will be performed. The purpose of the second phase is to ensure that the subsystems are capable of performing the higher level functionality necessitated by spacecraft operations. PANSAT project members will serve as test operators, conducting specific tasks and recording the results for inclusion in a test report at the conclusion of the test plan. [Ref. 2, p. 2]

E. SUBSYSTEM TESTING

Individual subsystems will undergo environmental testing in a similar fashion to the system level tests. For example, tests will be conducted on the batteries, the mechanical housing, and the EPS. Tests have already been completed on the solar panels, with each individual panel being subjected to an environmental test. An aggressive strategy to satellite subsystem testing will hopefully help to minimize unwanted surprises at a later point in time.

VII. COMMAND GROUND STATION

A. DESCRIPTION

The command ground station for the control of PANSAT will be located in the NPS SSAG and will be managed and maintained by students, staff, and technicians. A typical amateur radio satellite terminal setup, as shown in Figure 7.1, will be used for control and will consist of the following components [Ref. 1, pp. 7 and 59]:

- Personal computer (PC) running terminal and communications software, enabling NPS to conduct all required ground control functions;
- Terminal Node Controller (TNC) which transforms PC data into the AX.25 packet format;
- Transmitter;
- Receiver;
- Spread spectrum and narrowband modem, and
- Antenna system and rotors for tracking functions.

The framework for the command ground station already exists at NPS. The SSAG has an operating base station that is used to communicate with amateur satellites currently in orbit. The current base station will have to undergo a few minor modifications in order to make it compatible with PANSAT, with the most notable being the incorporation of PANSAT-specific software. Figure 7.2 shows PANSAT's command ground station software. [Ref. 2, pp. 40-41]

B. COMMAND OPERATIONS

The command ground station will perform satellite commands, pass messages, control an open loop tracking antenna, and gather, display, and archive telemetry data and

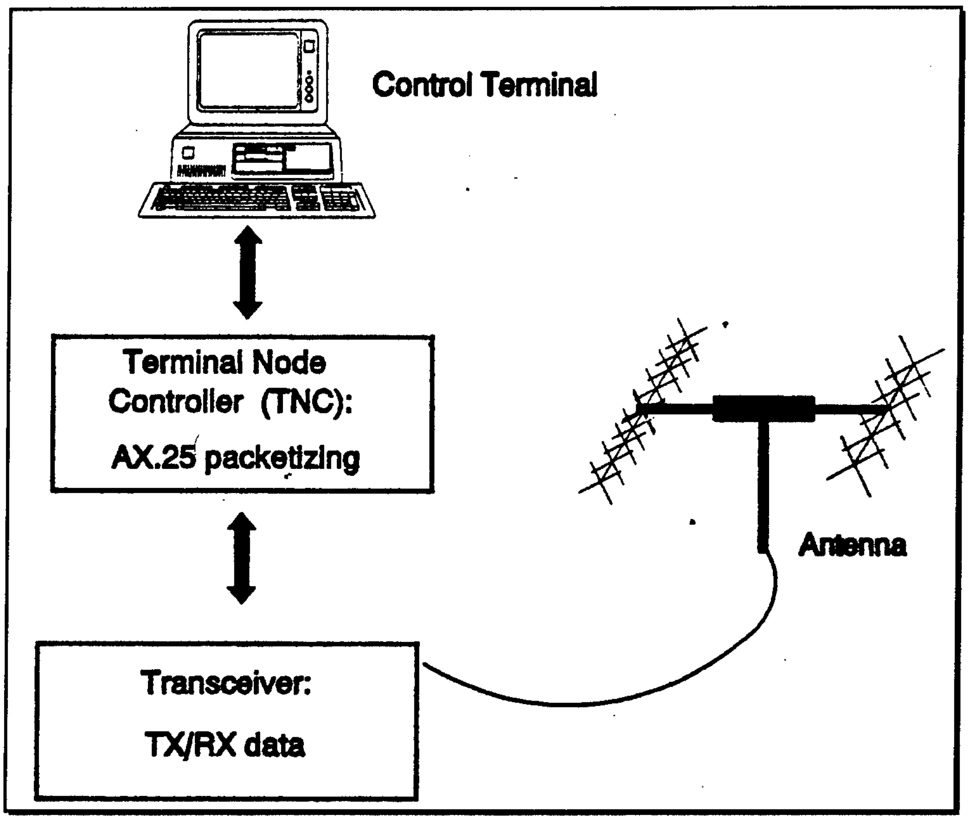


Figure 7.1 Functional Arrangement of Command Ground Station [Ref. 1, p. 8]

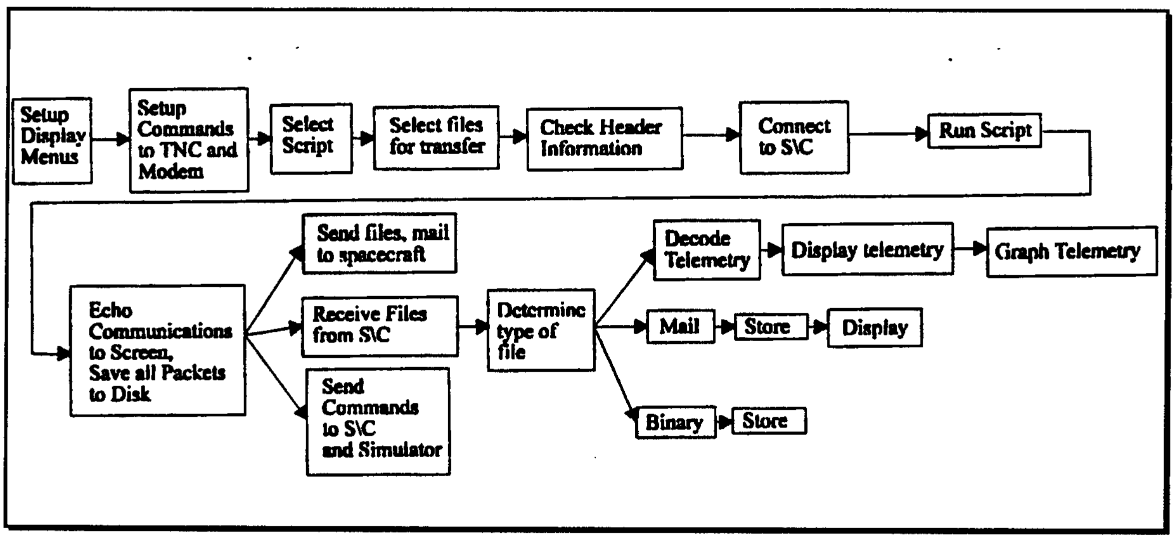


Figure 7.2 PANSAT Command Ground Station Software [Ref. 2]

messages. The telemetry will contain information concerning numerous items, including [Ref. 3, pp. 5-6]:

- values for all on-board sensors,
- packet radio statistics,
- mail and file exchange activities,
- status of on-board tasks, and
- additional characteristics that describe the state of the satellite.

Although any telemetry point can be downloaded to the NPS ground station, a minimal set of telemetry will be routinely gathered and stored by PANSAT. This list of telemetry and the frequency with which the items are gathered can be modified via ground command.

PANSAT is launched with minimal software and must undergo an initialization period, during which additional software is uploaded by the master ground station, before users can begin to interact with the satellite. Once the operating system and other software tasks are uploaded from the ground station, the satellite attains full operation and can begin conducting packet radio functions, ground station command functions, and telemetry down-loading. [Ref. 3, pp. 5-6]

The NPS ground station will also be used to command the spacecraft's subsystems, as they may need direct commanding from the ground to enable certain vital functions like battery discharging, modification of transmitter amplification, or control change to allow a redundant subsystem component to become operable. During the course of normal operations, PANSAT may go for extended periods of time without connecting with the NPS ground station. If this interval exceeds three days, PANSAT, in its proposed configuration, will cease all services with general users until contact is re-established with NPS. Preferably, the ground station will connect with PANSAT within the confines of this time frame, thus enabling any necessary management and/or maintenance functions to be executed. It is the author's opinion that perhaps the software

should be written to allow PANSAT to cease all services with users with the exception of continuing to send general telemetry. Ideally, users would inform NPS of PANSAT's degraded operation and corrective action could be initiated. The proposed software design allows PANSAT and the ground station to operate in conjunction to periodically free mass storage space by purging out-of-date mail and files. Furthermore, the NPS ground station will be able to upload software to the spacecraft, giving PANSAT the ability to correct software deficiencies and take advantage of new software. [Ref. 3, pp. 1-6]

VIII. LAUNCH OPTIONS

The Department of Defense (DOD) Space Test Program (STP) is responsible for acquisition of payloads for space flight, for actual space flight assignment for chosen payloads, and for eventual payload integration. The process commences with the filing of the STP Request for Space Flight, DD Form 1721, which contains information that helps determine the experiment's requirements and thus the preferred launch vehicle. Information includes orbit parameters, experiment orientation, power requirements, and mode, which is either as a sortie (retrieved), or as a free-flier (not retrieved). The objectives of the proposed experiment are also outlined in DD Form 1721, especially regarding their military relevance. Approved projects are reviewed on an annual basis through the Navy Call for Experiments, followed by the DOD Space Experiment Review Board (SERB), where sponsoring agencies brief their experiments and the experiments are assigned a ranking on the STP experiment priority list. The ranking is based on the Board's assessment of the experiment's DOD relevance, as well as on experiment quality and internal service priority. The STP experiment cycle is shown in Figure 8.1. [Ref. 1, pp. 4-5 and Ref. 2]

Due to its petite stature, PANSAT is suitable for launch by a variety of platforms, including the Space Shuttle, Pegasus, Scout, Delta II, Titan II, Taurus, and Minuteman II/III. NASA launches the Space Shuttle on a frequent basis, thereby providing numerous opportunities for manifest by secondary payloads. A Minuteman II/III launch, however, would allow PANSAT primary payload status. This offers greater control over launch vehicle operations. Recent developments in the Minuteman II/III make it a viable alternative, but the preferred method of orbit insertion is still the Space Shuttle. Prior to launch on the Space Shuttle, PANSAT will be transported from Monterey, California, to the Goddard Space Flight Center (GSFC), where it will undergo integration with the GAS canister. The canister, with PANSAT inside, will then be transported to Cape Canaveral, Florida, for final integration.

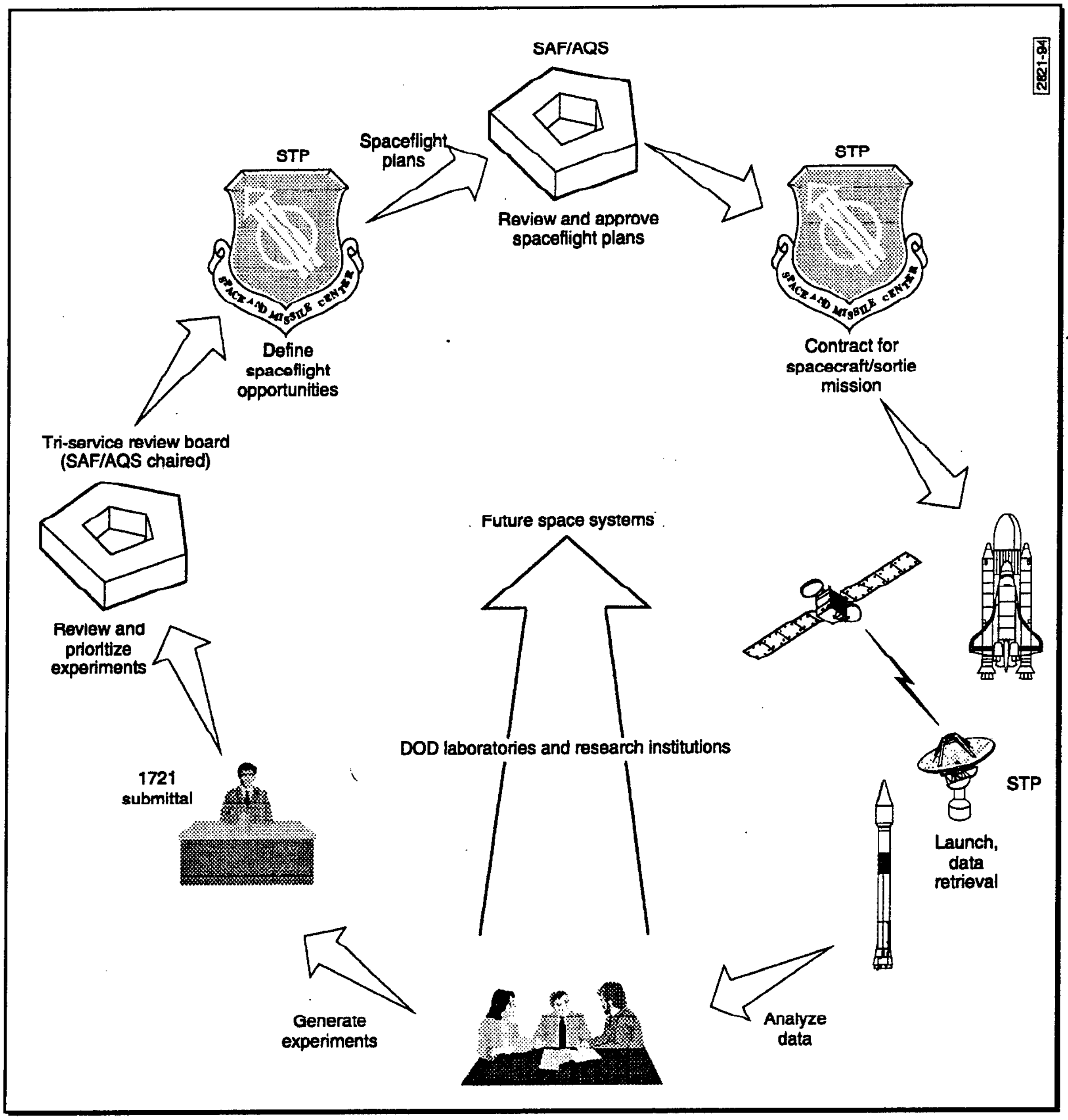


Figure 8.1 STP Experiment Cycle [Ref. 2]

A. SPACE SHUTTLE

1. Small Self-Contained Payload (SSCP)

If the determination is made that the payload will fly in a GAS canister, payload representatives will correspond directly with the NASA GAS program office, located at Goddard Space Flight Center (GSFC). The GAS program office is tasked with ensuring that the requirements set forth by NHB 1700.7B, *Safety Policy and Requirements for Payloads Using the Space Transportation System (STS)*, are met. Documentation requirements, including the Payload Accommodations Requirements (PAR) and the Safety Data Package (SDP), are covered in detail in Appendix A. [Ref. 1, p. 5]

PANSAT will most likely fly on the Space Shuttle as a Small Self-Contained Payload (SSCP), which utilizes the Get Away Special (GAS) and the Hitchhiker (HH) programs. Both HH and GAS payloads are loaded into GAS canisters, which are located in the cargo bay of the Shuttle. PANSAT will require a modified GAS canister (see Figure 8.2), to include a motorized door assembly and a launch mechanism, and will fly as a free-flier experiment. As stated previously, PANSAT would likely qualify as a secondary payload for other launch platforms, such as Scout and Pegasus, due to the conservative nature dictated by the SSCP design constraints. [Ref. 1, pp. 1-3]

The NASA standard ejection mechanism for GAS launches consists of a pedestal, a spring-loaded plunger, a 9-in.-diameter Marman Clamp retention system, and two pyrotechnic guillotine cutters that sever two bolts and release the Marman clamp. When released, the spring pushes the payload out of the canister at approximately 3.5 feet per second. [Ref. 1, p. 5]

PANSAT will be in a dormant state inside of the GAS canister while the Space Shuttle is ascending. The canister, although not insulated, provides the requisite thermal protection for the payload by utilizing heaters/thermostat control as well as heat removal by radiation. The canister is a pressure vessel that is capable of near vacuum to about

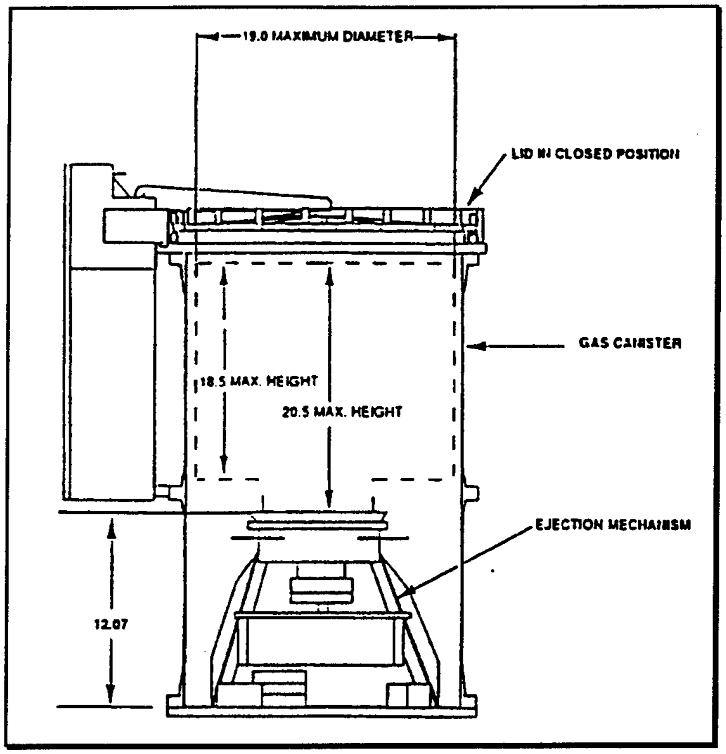


Figure 8.2 Modified GAS Canister [Ref. 3, p. 4]

one atmosphere at all times. Depressurization of the canister, which is necessary prior to door operation, occurs during Shuttle ascent, with the pressure falling from atmosphere to vacuum in approximately 100 seconds. [Ref. 4, p. 4]

2. Release Point in Orbit

As a GAS or HH payload riding in the GAS canister, PANSAT is considered a secondary payload and accordingly will have to accept whatever orbital elements that the primary payload demands. The requested, but not guaranteed, orbital insertion point would occur in the first five minutes of the sunlit portion of the orbit. PANSAT would then be ejected with its separation velocity vector coaligned with the sun vector. The altitude and inclination will fall somewhere in the advertised range of Space Shuttle operations, which is between 110 NM (203.7 km) and 330 NM (611.2 km) for altitude, and between 28.5° and 57.0 ° for inclination. Assuming orbital insertion via the September 1997 STS-86 launch, PANSAT will be placed into an orbit with an altitude of

about 210 NM and an inclination of approximately 52°. The actual orbital elements for each mission depends on the mass of the payloads and on the number of installed orbital maneuvering systems kits. [Ref. 5, p. 4]

B. MINUTEMAN II/III

The Multi-Service Launch System (MSLS) is a proposed USAF Rocket Systems Launch Program with 450 Minuteman (MM) II assets available. Use of these Inter-Continental Ballistic Missile (ICBM) assets requires congressional approval which at this time is still forthcoming. The MSLS MM II/III can be used in a number of different configurations, including sounding rockets and space launch vehicles. The reliable, cost effective space launch vehicles utilized by this program maximize use of proven off-the-shelf hardware. Features include flexible interfaces, multiple launch sites, low development cost, low infrastructure cost, low launch cost, and low risk. Figure 8.3 shows the MSLS launch vehicle configurations and Tables 8.1 and 8.2 show the MSLS Configurations B and D payload to orbit performances in pounds. A 90° inclination is assumed for a launch from the Western Test Range (WTR), while a 28.5° inclination is assumed for a launch from the Eastern Test Range (ETR). [Ref. 6]

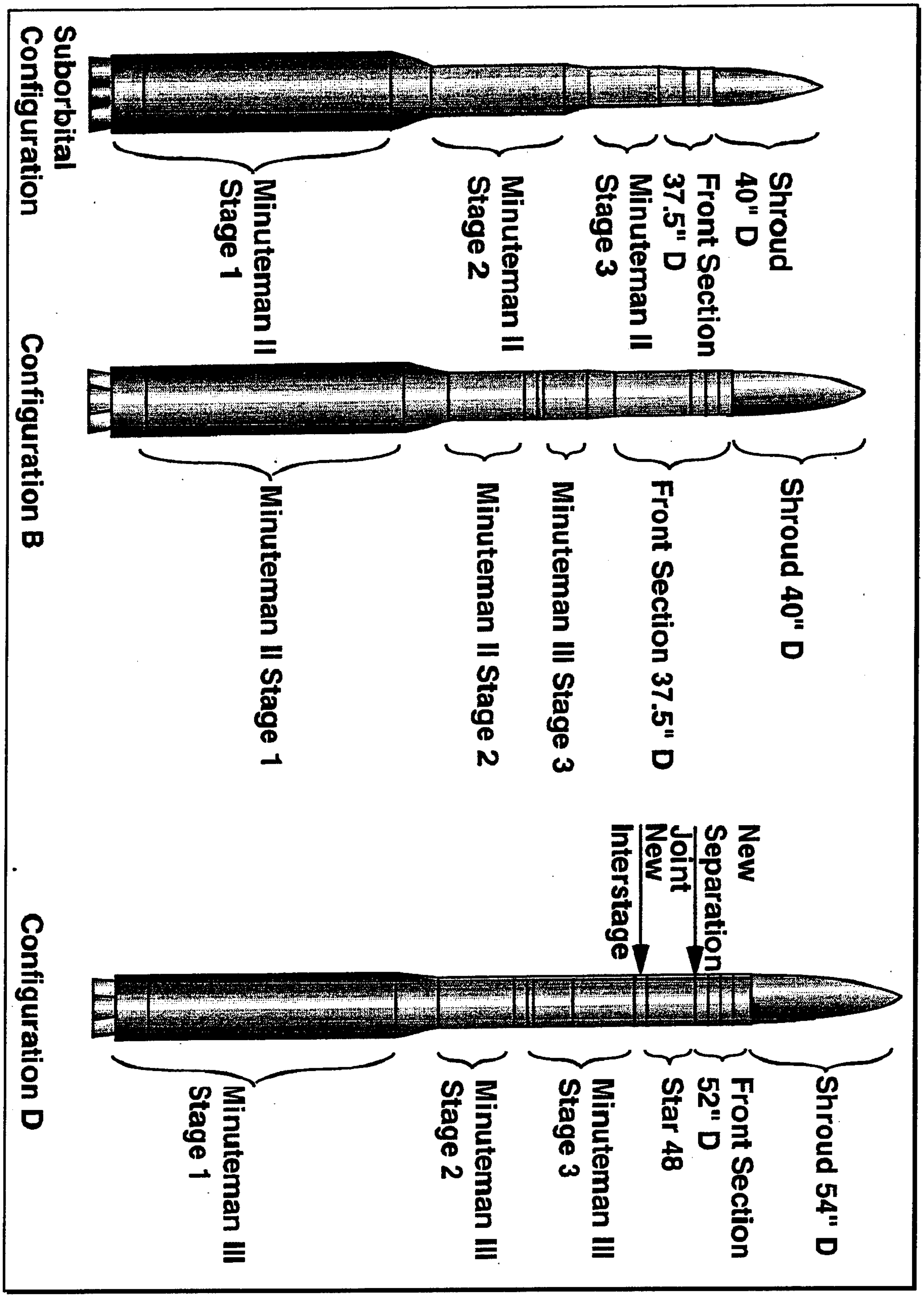


Figure 8.3 MSLS Launch Vehicle Configurations [Ref. 6]

	Payload (lbs) to Orbit from:	
Orbit Altitude (NM)	**WTR - 90°**	**ETR -28.5°**
100	417	742
200	343	652
300	280	575
400	224	506
500	174	442

Table 8.1 MSLS Configuration B Payload to Orbit Performance (lbs) [Ref. 6]

	Payload (lbs) to Orbit from:	
Orbit Altitude (NM)	**WTR - 90°**	**ETR -28.5°**
100	759	1090
200	634	939
300	521	826
400	432	704
500	351	630

Table 8.2 MSLS Configuration D Payload to Orbit Performance (lbs) [Ref. 6]

IX. ON-ORBIT OPERATIONS

The stage in PANSAT's life cycle referred to as on-orbit is defined as the time period which commences with the opening of the GAS canister lid and ends with PANSAT's reentry into the Earth's atmosphere. Subsequent to the opening of the motorized doors, two pyrotechnic bolts will fire, releasing the Marman clamp, which connects the pusher plate to the satellite. This sequence of events allows PANSAT to separate from the Space Shuttle and enter its own orbit. Launch plate separation activates four microswitches and closes a circuit to begin providing power to the EPS. The microswitches are wired as two parallel strings, with two microswitches in series in each string. The EPS uses its solar arrays to charge the batteries to the level necessary for operation, after which power is provided to the DCS and COMM subsystems. At startup, PANSAT will occasionally monitor to see if NPS is attempting to communicate. [Ref. 1, p. 6]

PANSAT is launched with minimal software and must undergo an initialization period, during which additional software is uploaded, before users can begin to interact with the satellite. Once the operating system and other software tasks are uploaded from the ground station, the satellite will attain full operation and can begin conducting packet radio functions, ground station command functions, and telemetry down-loading.

A. OPERATING PROCEDURES

With the Ham operator's ground station properly configured for use with PANSAT, communications and operations will follow the standard operating procedures that are used with most other amateur satellites. The user will simply determine, from within the software package and through the use of menus and linked software programs, when the satellite will be in view and therefore accessible. When satellite pass has been determined, the software package allows the user to select automatic tracking when the user's physical location is within the footprint of the satellite. Once satellite contact has

been established and control settings have been verified, operating procedures then encompass simple user manipulation of the software menu system. [Ref. 2, pp. 50-51]

Reception and processing of PANSAT transmissions by ground stations are handled by the receiving software module. Once the user activates the REC (receive) command, the receiving software will automatically download information from a communicating satellite and then process the data as instructed by the user. Most software packages allow implementation or receipt of numerous options, including the following [Ref. 2, pp. 50-51]:

- Priority - allows the user to place some messages before others in the automatic downloading system.
- Auto - indicates that the message will be completely downloaded and filed automatically.
- Grab - indicates that the message will be saved if it is overheard when another station is downloading it.
- Never - indicates that a message will not be automatically downloaded and filed, nor will it be saved.
- Fill - broadcast command which tells the satellite to transmit an entire message if the requesting station has not received any part of it.
- Dir - broadcast command which sends a request to the satellite to update the requesting station's directory.
- Broadcast Queue - a list of those stations whose requests for broadcast are currently being processed.

In order for a user to send mail or files, the item to be transmitted will have to be prepared by the software package and the antenna will have to begin tracking the satellite. The transmission software module will then pass the prepared message to the ground station equipment and the message will be transmitted. [Ref. 2, p. 51]

The on-orbit operations test plan defines the operation and functionality of PANSAT on orbit. PANSAT's operational mission can be broken down into four distinct

modes: launch vehicle separation, spacecraft initialization, system evaluation and controlled testing, and operational user services. Subsequent to PANSAT's becoming operational for user services, the satellite will still have to be evaluated, controlled, and tested by the NPS ground station. While on orbit, PANSAT will be operated to ensure operational performance of the spacecraft system. [Ref. 3]

The on-orbit operations test plan covers the spacecraft initialization sequence and includes initialization, the power-up and reset sequence, DCS startup, and operating system and software tasks uploads. Operational user services require further definition and a memorandum of understanding should be developed with the Air Force and Naval Academies. Coordination between NPS and the academies is essential to the ongoing educational aspects of the project. [Ref. 3]

B. SIMULATOR

A simulator is being developed to allow PANSAT to interface with the command ground station. The simultaneous development and co-location of the simulator and the command ground station will greatly enhance near real time diagnostic and prediction analyses. The plan is for the simulator to be as functionally identical to the PANSAT as possible; ideally, the physical configuration of the simulator will mirror that of the satellite. The simulator's subsystems will physically interface with a personal computer (PC), or a workstation. This interface will allow simulation of the spacecraft's environment and operating modes so as to aid in providing assorted mission essential capabilities, including [Ref. 2, p. 51]:

- Allowing software engineers the ability to test software configuration changes prior to upload.
- Conducting diagnostic troubleshooting utilizing an archived telemetry database.
- Conducting life-cycle trend analysis in order to predict future satellite and satellite subsystem behavior.
- Scheduling and validating corrective actions (system work-arounds).

- Verifying pass commands and reconfiguration scripts by utilizing the most current known spacecraft configuration.
- Validating and refining system operating procedures (OP).
- Validating and refining system casualty procedures (CP).

One of the purposes of the simulator is to allow terrestrial modeling and simulation of inferred spacecraft conditions. Commanding or other critical operations which have the potential to cause undesired spacecraft reactions are first tested on the simulator. The possibility of induced failures on the satellite and subsequent failure work-around is thereby minimized. Additionally, the simulator is a valuable tool for the mission operators and system engineers to conduct necessary testing. [Ref. 2, p. 53]

C. PANSAT ORBITAL DECAY

1. Reentry

Since PANSAT incorporates neither an attitude control subsystem nor a propulsion subsystem, both of which would aid in orbit maintenance and flight duration, orbit lifetime will be determined by the rate of orbital decay. PANSAT will eventually reenter the Earth's atmosphere in the final phase of its life span, which is commonly referred to as the "reentry phase." The trajectories experienced by spacecraft during reentry to the Earth's atmosphere can be classified as either controlled or uncontrolled. A controlled reentry occurs when the spacecraft's aerodynamic and heating loads are low enough to allow the vehicle to survive reentry and land on the surface of the Earth. A controlled reentry can be achieved by manipulating the lift and drag forces, thereby controlling the flight path angle and the aerodynamic and heating loads experienced by the vehicle. An uncontrolled trajectory, or uncontrolled reentry, is typically the path followed by unrecoverable satellites reaching the end of their operational lives. Such reentries are typified by negligible spacecraft lift capabilities and flight path angles generally much smaller than 1°. [Ref. 4, p. 53]

The physical characteristics of PANSAT provide virtually zero lift, so the spacecraft will follow the trajectory of a decaying orbit classified as an uncontrolled reentry. The major elements that illustrate uncontrolled reentry and consequently influence spacecraft survivability during the reentry phase are:

- a rapid decrease in altitude,
- an abrupt increase in aerodynamic heating loads, and
- a significant increase in aerodynamic loads.

PANSAT's uncontrolled reentry can be divided into two segments: flight before satellite breakup and flight after the breakup has occurred. Satellite breakup is defined as the point in the trajectory where aerodynamic heating and loading cause the structural integrity of the spacecraft to undergo catastrophic failure. [Ref. 4, p. 54]

2. Structural Failure and Survivability to Impact

The numerous dynamic processes normally encountered during reentry will hopefully result in a breakdown in PANSAT's structural integrity. Breakdown may or may not cause complete destruction of all external and internal components. The dominant factor controlling structural failure is the spacecraft's ability to exceed its melting temperature, which is a function of heating rate and ballistic coefficient. An Aerospace Corporation study determined that consistent catastrophic failure of aluminum structures occurs at an altitude of 42 NM for ballistic coefficients of 15 lb/ft^2 or greater. [Ref. 4, pp. 60-64]

PANSAT is expected to encounter aerodynamic heating and structural loads during reentry that will be of sufficient magnitude to cause failure of the outer casing. However, the possibility that internal materials of the satellite will survive to impact must be taken into consideration. PANSAT subcomponents may have ballistic coefficients low enough to allow them to rapidly decelerate through their peak heating and subsequently remain intact and impact the Earth. It has been shown that objects with

ballistic coefficients lower than approximately 15 lb/ft^2 for aluminum structures typically survive the reentry phase. The melting temperature of the internal materials also factors into survivability. On occasion, circuit boards have survived reentry, showing minimal evidence of heating, and have only been identified as reentry debris by association with a suspected satellite impact area. Aerospace Corporation proposed the following criteria for survival [Ref. 4, p. 63 and Ref. 5, p. C9]:

- ballistic coefficient and material of objects dictates survivability;
- objects with low ballistic coefficients typically survive;
- objects with high melting temperatures can survive with higher ballistic coefficients;
- survivability of objects is much greater than has been and continues to be analytically predicted.

The accurate prediction of potential impact areas is essential due to the possibility of casualties and property damage from orbital debris. There have been many attempts to analyze reentry hazards, including the use of random reentry risk reevaluation programs. Risk predictions were reviewed in an Aerospace Corporation study, which utilizes a program called LIFETIME 4.1. LIFETIME 4.1 analyzes the risk predictions, in conjunction with a host of other factors, and provides an estimate of satellite orbital life in addition to anticipated latitude and longitude of the impact footprint. After PANSAT has been launched and the release point has been verified, the data can be input to the LIFETIME program. Ideally, adequate time will be available for notification of the potential debris impact area. During the course of its mission life, PANSAT's updated orbital elements may be input to the LIFETIME program in order to attain the most up-to-date status concerning the satellite's lifetime as well as eventual impact area. [Ref. 4, p. 64]

X. BUDGET INFORMATION

From the onset of the project, the PANSAT budget has been geared towards low cost. Due to the length of the project, modifications/additions to the original design, and the impact of inflation, the price tag for PANSAT has risen to more than two million dollars. Table 10.1 shows a summarized PANSAT spreadsheet, breaking down the monetary expenditures by fiscal year and major category. Fiscal years 1990 through 1995 reflect actual documented costs, while fiscal years 1996 and 1997 represent estimated costs.

FISCAL YEAR	FACULTY LABOR	STAFF LABOR	HARD-WARE	YEAR TOTAL	GRAND TOTAL
1990	$0	$41,286	$100,000	$141,286	$141,286
1991	$0	$54,432	$150,000	$204,432	$345,717
1992	$0	$109,532	$150,000	$259,532	$605,249
1993	$32,600	$177,842	$176,000	$386,442	$991,692
1994	$73,525	$214,961	$130,000	$418,486	$1,410,178
1995	$54,101	$271,884	$90,000	$415,985	$1,826,163
1996	$56,806	$246,351	$40,000	$343,158	$2,169,321
1997	$59,647	$281,932	$40,000	$381,579	$2,550,900
Total cost excluding facilities expenditures:					**$2,150,900**

Table 10.1 Budget Information [Ref. 1]

The faculty and staff labor figures reflect payroll expenditures to the personnel involved in the PANSAT project. To arrive at these values, the salaries of the contributing individuals were pro-rated so that only the time they actually spent working on PANSAT was factored into the budget. Personnel time and the corresponding pro-rated salaries from work conducted in other areas of the SSAG were not used in the budget computations. Additionally, time is often spent by professors advising theses that

initially support PANSAT, but end up dealing with different and sometimes altogether unrelated subjects. This equates to salary outlays for work that in actuality should not be counted against the PANSAT project. Students participated in the project, but since their salaries were/are provided by their military services, their salaries were not counted against PANSAT.

The hardware figures include equipment and facilities in addition to actual satellite hardware. Of note is the fact that all of the hardware expenditures in fiscal years 1990 through 1992, i.e., $100,000.00 + $150,000.00 + $150,000.00 = **$400,000.00**, went toward the buildup of facilities within the SSAG at NPS. The PANSAT project humbly began in a two-room office with two engineers and has matured into an integration facility and a precision fabrication facility staffed by six engineers and a machinist/model maker. Additional outlays for facilities, albeit small by comparison, have occurred over the course of the project. The acquisition of these facilities was necessary for the conduct of the project; however, the costs associated with their purchase, installation, and upkeep account for approximately 20% (more than $400,000.00 of the $2,550,900.00) of the total budget. The facilities remain in place, are currently being utilized for course laboratories, and are readily available for future projects, so their price tag/worth cannot be judged solely on the basis of their impact on the PANSAT budget.

XI. RECOMMENDATIONS/CONCLUSIONS

A. FUTURE DIRECTIONS

From the present time to the end of the project and with design and fabrication issues mostly frozen, certain issues require special attention. These include integration, testing, and operations issues. In addition, further research is necessary into areas such as potential applications of the satellite, follow-on programs, and internet access.

1. Potential Applications

The potential applications for PANSAT technology are varied and widespread, with two of the more notable examples being the U. S. Coast Guard and the Department of the Interior. PANSAT could be used to aid the U.S. Coast Guard with the collection of status information from buoys along the Atlantic and Pacific Coasts. Each buoy would have to be retrofitted with a small Global Positioning System (GPS) equipped transmitter which would enable up-linking, on a routine basis, of buoy location, battery status, and light bulb status. Physical inspections of each buoy by way of maintenance visits would thereby be minimized. The status information could be downloaded to a buoy control center, which would facilitate centralization and automation of the buoy monitoring process. [Ref. 1, pp. 39-40]

The Bureau of Land Management and other bureaus within the Department of the Interior have numerous field teams working in remote locations. In many instances, communication between field parties and their respective headquarters is non-existent due to distance and technological limitations. These field work parties could use PANSAT's store-and-forward system to communicate with their parent headquarters. [Ref. 1, p. 29]

2. Follow-On Programs

The facilities which were acquired and/or built for the PANSAT project remain in place and are readily available for use in future endeavors. In fact, they are currently

being used by the SSAG for course-related work and laboratories. Their cost has been absorbed by the PANSAT project and it would be a waste to not further utilize these invaluable assets. The existing infrastructure is manned by engineers/technicians familiar with the layout and operations. With the framework and personnel in place, all that is required is a follow-on project to keep them gainfully employed once PANSAT has been launched and reaches the end of its anticipated two year service life.

3. Topics Requiring Further Study

The development of a World Wide Web (WWW) interface for PANSAT would allow users to browse through documentation concerning PANSAT at their leisure. The internet caters to a large number of people, which could be an excellent means of advertising PANSAT. Interested parties could access information about the satellite at any time of day, from the comfort of their own workspace, and PANSAT could attain international acclaim. Portions of this undertaking are currently underway.

Over the course of the PANSAT project, numerous design and program issues have been decided and are common knowledge to the involved engineers. Unfortunately in the early stages of the program not all of these decisions were fully documented. The commencement of documentation efforts, like the implementation of meeting minutes, have made great strides towards alleviating this shortcoming, but more work in this area remains. The development of decision trees and flow charts representing the project in its entirety might prove to be useful tools for further endeavors. A great deal can be learned from analyzing historical data such as that found in carefully prepared matrices and graphs.

Additional recommendations concerning policy and documentation can be found at the end of Appendix A. Appendix A deals specifically with policy and documentation requirements.

B. WHAT DID WE LEARN?

1. Scheduling

The PANSAT project is an example of the lack of predictability in the scheduling of events. Despite even the most thorough planning and meticulous calculations, almost every program tends to slip behind schedule at some point in time. The majority of programs never catch up once they begin to slide behind schedule; in fact, unforeseen events and unexpected delays oftentimes pitch in and exacerbate the situation. Scheduling difficulties resulted in perceived setbacks in PANSAT's development, but one could make the argument that PANSAT scheduling was unrealistic due to the fact that the program was not always charting a steady course. Numerous design changes occurred during all phases of development, with the end result being that events actually drove the schedule.

When dealing with schedules and with timelines, a good rule of thumb would be to double the time/due date estimates. Coming in ahead of schedule is more desirable than coming in behind, as is most often the case, and allows leeway for unforeseen circumstances. Evaluation of past performance concerning the source of the estimate is also a good practice and allows the scheduler to hopefully generate a more accurate and realistic schedule.

In the scheduling realm, the integration period for PANSAT must not be dismissed. To make a September 1997 launch, PANSAT will have to be ready for shipping in February of 1997, in order to allow for transportation time, processing, and integration. Goddard Space Flight Center requires six months integration time on site and the Kennedy Space Center calls for one week. These are firm requirements so PANSAT must be ready for transportation in February or another launch date and/or vehicle will have to be arranged.

2. Testing

Although the Hitchhiker test requirements are quite extensive, the PANSAT engineers are conducting additional testing. This extra testing is self-imposed and is above and beyond the basic requirements. The PANSAT team wants their handiwork to function when it gets on orbit and they are doing everything in their power to ensure that this occurs. The ability to launch a small payload to orbit within a short time period and a very limited budget is desirable; the ability to do this safely and on the first attempt is admirable.

4. Technology

The influence of technology on PANSAT was, for the most part, positive, but when new technology is introduced certain trade-offs are incurred. The overriding desire is to accept the latest and greatest, but this is not always the best course of action. The addition or modification of components results in a plethora of changes in a wide variety of areas. Depending on where a project is in development, the changes required by accepting new technology may outweigh the advantages gained. Careful analysis must be conducted and an informed, educated decision must be made.

3. Budget

PANSAT, with a cost of about two million dollars, is a low cost satellite. The facilities required to support this venture remain in place for future projects. The purchase and installation of facilities at the onset of the project accounted for approximately 20% of the total budget. Early PANSAT-related theses predicted the program cost to be in the $500,000 to $800,000 range. The price increase is the result of many factors, not the least of which is inflation. Additionally, the length of the project was initially expected to be on the order of three to four years, but that timeframe has been stretched out and is anticipated to be eight or more years by the time the satellite is launched. This elongation of the project duration results in additional staff and faculty

labor costs, further adding to the budget escalation. The bottom line, however, is not about money. It is about the purpose behind the PANSAT project, which is to assist in the education and development of officer students. Even though extending the lifetime of the program adds to the overall costs, it provides opportunities for a greater number of students to obtain educational benefits.

APPENDIX A. POLICY AND DOCUMENTATION

A. PURPOSE

Safety policy, requirements, and documentation applicable to the Space Transportation System (STS) are complicated and time consuming, but "are intended to protect flight and ground personnel, the STS, other payloads, ground support equipment (GSE), the general public, public and private property, and the environment from payload-related hazards." [Ref. 1, p. 7] In this chapter, policy is reviewed and documents required by the governing agencies are listed and defined. The specific aspects that will be covered are as follows:

- Documentation required by NASA (safety, CPR, etc.),
- Keps request form (for Det 2),
- Documentation for FCC,
- Ham policy on s/c communications, and
- Graphic portrayal of a chronological timeline for documentation.

According to JSC-21000-IAP, "the customer is responsible for certifying that the payload is ready to fly . . . and must ensure through the joint documents (i.e., PIP, PIP Annexes, and ICD) that their requirements are well defined and correct." The customer tackles this task by closely following established policy and completing all required documentation. Careful attention to detail and timeliness are essential to the safety of the shuttle and its crew; henceforth, safety issues, no matter how small, should be at the forefront of every aspect of the operation. Insofar as safety is concerned, one's guard must never be let down and the customer must always remember that "safety is an ongoing process that is integral to all payload/STS integration activities." [Ref. 2, p. 13] Safety is at the top of the staircase, and policy and documentation form the steps that lead to that ideal.

B. POLICY DOCUMENTS

The list of documents pertaining to policy is quite extensive; Table A-1 on the following pages lists a few of the more notable documents and provides a brief overview of their contents.

Policy Document	Name	Overview
CARS HHG-730-1503-07	Customer Accommodations and Requirements Specifications 1994	•defines available standard interfaces and services provided by the Hitchhiker (HH) carrier systems, the Shuttle Small Payloads Project (SSPP), the Shuttle Program, and NASA to a HH payload customer. •defines requirements to be met by the customer in areas such as interfaces, environmental capability, Electromagnetic Interference (EMI) control, and safety. •defines customer and NASA responsibilities for the different phases of the mission. •appendix A contains Payload Safety Requirements. •appendix B contains information on the different materials acceptable for the HH program. •appendix E contains the Customer Payload Requirements (CPR).
JSC-21000-HBK	STS Customer Accommodations - A Handbook for Space Shuttle Users May 1986	•provides an overview of the STS and its payload accommodations to support the conceptual design of payloads and their integration into the space shuttle. •serves as a guide to documents that further define design and operational requirements for space shuttle payloads. •contains discussions on: the STS, STS performance capabilities, payload accommodations, STS customer documentation, the payload integration process, and pricing summaries. •document references three categories of STS accommodations for payloads: standard, small, and middeck.
JSC-21000-SCA	STS Customer Accommodations Document	•provides a general description of the STS and data on the STS flight and ground systems.

Table A-1. Policy Documents

Policy Document	Name	Overview
NHB 1700 Vol. I	NASA Basic Safety Manual	•covers NASA's guidelines on safety issues.
NSTS 1700.7B	Safety Policy and Requirements for Payloads using the STS January 1989	•National Space Transportation System (NSTS) safety policy is to maintain the assurance of a safe operation while minimizing NSTS involvement in the design process of the payload and its GSE. •allows the payload organization the latitude to determine the best design to meet mission objectives while maintaining compliance with the overall NSTS safety policies and requirements. •identifies the safety policy and requirements which are to be implemented by the payload organization. •establishes both technical and system safety requirements for STS payloads. •applies to flight operations, ground operations, and payload hardware, including new designs, existing designs (re-flown hardware), and hardware designed similarly for commercial use.
NSTS 13830 Rev. B	Implementation Procedure for NSTS Payloads System Safety Requirements	•jointly issued Johnson Space Center (JSC) and Kennedy Space Center (KSC) document. •published to assist the payload organization in implementing the system safety requirements. •further defines the safety analyses, data submittals, and safety assessment review meetings. •identifies the respective roles of the NSTS flight operator and the NSTS launch / landing site operator. •reflects a basic policy of commonality, compatibility, and coordination between the NSTS flight and ground elements in the implementation effort. •contains payload safety verification tracking log (VTL). •provides detailed instructions for the safety analysis and the safety assessment reports.

Table A-1. Policy Documents (cont.)

Policy Document	Name	Overview
NSTS 13830 Rev. B (Cont.)	Implementation Procedure for NSTS Payloads System Safety Requirements	•describes a safety analysis which shall be performed in a systematic manner on each payload, its GSE, related software, and ground and flight operations in order to identify hazardous subsystems and functions. •details a safety assessment report which documents the results of the safety analysis, including hazard identification, classification, and resolution, and a record of all safety-related failures.
NSTS 14046	Payload Verification Requirements	•identifies structural integrity requirements for external load environments.
NSTS 18798A	Interpretations of NSTS Payload Safety Requirements	•collection of interpretations of requirements relative to specific payload designs.
JSC 20793	Manned Space Vehicle, Battery Safety Handbook	•establishes safety guidelines for STS payload batteries. •mandates extensive testing and analysis when lithium batteries are used.
SAMTO HB S-100/ KHB 1700.7 Rev. B	Space and Missile Test Organization (SAMTO) and Kennedy Space Center (KSC) Handbook / Space Transportation System Ground Safety Handbook	•covers additional safety requirements which are unique to ground operations and GSE design. •joint handbook prepared by SAMTO and KSC.

Table A-1. Policy Documents (cont.)

C. DOCUMENTATION REQUIRED BY NASA

NASA documentation requirements concerning Space Shuttle flights cover virtually every aspect imaginable. As stated previously, these stringent and comprehensive mandates are based upon critical safety concerns. Table A-2 on the following pages shows a few of the more noteworthy documents, furnishes their reference, or parent document, where applicable, and supplies a synopsis of their subject matter.

Document Number/ [Ref.]	Name	Purpose
CIR	Cargo Integration Review	•held approximately 7-1/2 months prior to flight. •ensures that the payloads selected to comprise the cargo can be physically and functionally integrated into a flight which is within the STS's flight and ground capabilities. •establishes the baseline flight event sequence. •provides the customers with insight into the integration of their requirements at the cargo / flight level. •chaired by the NSTSO Manager with board members from the STS elements and the customers. •results provide the implementing organization with the basic engineering, operational, and ground implementing activities. •when finished, final preparation for the mission begins. •completion of the CIR leads to a firm cargo manifest.
CPR-PAR/ [CARS]	Customer Payload Requirements/Payload Accommodations Report	•specifies all interface requirements and parameters. •contains thermal, mechanical, electrical, attitude control, alignment, test and checkout, contamination control, mission operations, and shipping and handling requirements. •also includes customer-prepared interface drawings and schematics. •defines which of the available carrier services and interfaces the customer needs and is requesting. •documents deviations from standard interfaces and services, which require specific authorization by the HH Project Office.

Table A-2. NASA Documents

Document Number/ [Ref.]	Name	Purpose
DD Form 1721	Space Test Program Flight Request August 1990	•provides overview of the system. •contains executive summary of program. •lists relevance to specific DOD requirements. •lists alternatives to space flight. •lists follow-on plans. •part 1 contains description of payload. •part 2 contains technical details such as flight date, orbital parameters, orbital orientation requirements, stabilization requirements, major movements, telemetry and data handling commands, possible hazards, etc. •part 3 contains program security information, funding breakdown, coordination, and security information. •this is the document that initiates the request process. •each individual service submits their space flight experiment request to the tri-service which then submits their recommendations for space flight experiments to NASA.
FCIP	Fracture Control Implementation Plan	•describes in detail how the requirements of the General Fracture Control Plan for Payloads Using the STS, 731-0005-83 Rev. B, will be satisfied. •provides assurance that no catastrophic hazards to the Shuttle Orbiter or crew will result from the initiation or propagation of flaws, cracks, or crack-like defects in customer structure during its mission lifetime, including fabrication, testing, and service life. •plan must be approved by Goddard Space Flight Center (GSFC) prior to implementation. •normally included as part of the SIVP.
FRR	Flight Readiness Review	•verifies that all of the STS / cargo integration activities have been completed. •certifies that all flight elements are ready to perform the mission. •conducted by NASA Headquarters and supported by all of the major STS elements. •held during the final month before launch.
GSFC-302-SS-02B	STS Payload Ground Safety Requirements Applicability Matrix	•part of the documentation required for payload safety requirements. •from Appendix A of CARS.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
ICD	Interface Control Document	•defines the detailed design interface specifications. •draft proposed by the STS with data provided by customer.
JSC FORM 542B	Payload Hazard Report November 1982 Revision	•completed for each hazard identified on the descriptive data form. •each hazard report should stand alone. •data required to understand the hazard, the hazard controls, and the safety verification methods should be attached to the report. •used to track hazards identified throughout the life cycle of the payload. •data is included in a Payload/HH combined Safety Data Package (SDP).
JSC FORM 542C	Payload Safety Non-compliance Report 1983 Revision	•a waiver request form submitted to GSFC for review when safety requirements cannot be met. •if waiver is denied, the customer must meet the safety requirements through design changes to the payload in order for it to fly on the STS.
JSC FORM 1090	NSTS Payload Safety Requirements Applicability Matrix	•part of the documentation required for payload safety requirements. •from Appendix A of CARS. •foresee and assess interrelationships between the basic hazard groups and subsystems contained in the payload.
JSC FORM 1090A	NSTS Payload Safety Requirements Applicability Descriptive Data	•provides a listing of the hazard groups applicable to each subsystem and cross-references each hazard to applicable technical requirement from NSTS 1700.7B and KHB 1700.7 Revision B.
JSC-21000-IAP	Shuttle/Payload Integration Activities Plan	•involves the design, analysis, verification, fabrication, and delivery of integration hardware, engineering products, and software.
JSC-21000-IDD-STD	Shuttle/Payload Interface Definition Document	•contains the standard payload accommodations. •defines those interfaces that are standard for the type of accommodations covered. •used as the basis for the customer-specific Interface Control Document (ICD).
JSC-21000-SIP-SML	Shuttle/Payload Standard Interface Plan for Small Payloads	•blank book utilized for documenting data. •templates for documents ease and hasten the process.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
LSA/ [JSC-21000-IAP, pg. 4]	Launch Services Agreement	•contractual agreement that covers the terms and conditions, legal liabilities, special fees, schedules, prices, and payment schedules. •developed and signed by NASA Headquarters and is co-signed by the customer. •provides an anticipated billing schedule for optional services.
MICD / [CARS]	Mechanical Interface Control Drawings	•vital document that states the mutual customer-NASA understanding in all mechanical interface areas such as hole location tolerances, hole diameter tolerances, interface plane flatness, interface plane finish, and interface thickness. •customer responsible for providing the drawings and other information required for GSFC to produce the MICD. •two sets of final detail fabrication and assembly drawings shall be provided to Goddard Space Flight Center (GSFC) for review and reference. •see Appendix A for required information.
MOA	Memorandum of Agreement Revision 2	•defines the relationship between the USAF Space and Missile Center/Space Test and Small Launch Vehicle Programs Office (SMC/CUL) and NPS on the terms and conditions for integration and spaceflight of NPS-901 (PANSAT) on the Space Shuttle. •establishes the basic working agreements between SMC/CUL and NPS. •specifically defines the responsibilities of SMC/CUL and NPS. •reviewed annually and amended as required. •the technical requirements listed form the basis for integration of NPS-901 onto the Hitchhiker carrier until the CPR document is completed. The CPR, once completed and approved, shall take precedence over the requirements listed in the MOA.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
ML/ [CARS]	Materials List	•a list of materials shall be submitted to GSFC as soon as possible. •allowable mechanical properties of structural materials shall be obtained from MIL-HBK-5D. •only materials with high resistance to stress, corrosion, and cracking listed in Table I of the latest version of MSFC-SPEC-522B shall be used.
NASA Form 1628 [CARS]	Request for Flight	•done by Air Force Space Test Program (STP). •initiates the payload integration process. •formerly known as NSTS 100
PIP	Payload Integration Plan	•joint STS and customer activity. •defines roles and responsibilities of the customer and the STS. •defines the technical baseline for implementation. •establishes guidelines and constraints for integration and planning. •defines integration tasks to be accomplished. •establishes operational service requirements. •establishes interface verification requirements. •establishes controlling schedules for all major integration activities. •references STS safety requirements. •establishes the basis for STS definition and pricing of optional services. •properly identifies the payloads' orbital requirements and constraints.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
PIP (cont.)	Payload Integration Plan	•control document for the joint development of the interface design as defined in the ICD and for the documentation of payload implementing data contained in the PIP annexes. •draft document is prepared which encompasses the payload / STS integration requirements and provides the format and general depth of content required for the particular payload. •initiates development of the integration activities schedule. •defines optional services to be provided to the customer, including a brief description, a preliminary price estimate, and a proposed schedule of activities for each optional service requested. •technical contract with the customer that contains the technical agreements by which the payload / cargo is integrated with the STS. •becomes technical contract when agreed to and signed by the Lyndon B. Johnson Space Center (JSC) National Space Transportation System Office (NSTSO) and the customer. •becomes part of the formal contract by reference in the LSA.
PIP Annexes	Payload Integration Plan Annexes	•established as the method for each customer to provide the detailed data required by the STS to configure flight and ground systems and to implement other integration functions as defined in the PIP.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
PIP Annexes (cont.)	Payload Integration Plan Annexes	•standard format for each annex has been prepared to facilitate the development of the required annexes. •payload data from these annexes are integrated with STS standard flight segments and procedures by the STS organization to develop documentation to implement flight and ground operations. •complexity of the payload determines the specific annexes required as well as the necessary degree of detail. •the annexes required and the schedule for submittal by the customer are defined in the PIP. **•Annex 1, Payload Data Package:** •provides detailed data on the physical characteristics of the payload. •includes a definition of the sequenced mass properties. •provides configuration drawings of all major payload elements. •contains radio frequency (RF) radiation data. •includes functional data on payloads. **•Annex 2, Flight Planning:** •provides the required flight design and crew activities planning data. •contains detailed flight profile (trajectory), launch window, and consumable requirements. •contains payload scheduling data which is used to develop the Crew Activity Plan (CAP), i.e., timeline data, scheduling constraints, pointing data, and crew payload support requirements.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
PIP Annexes (cont.)	Payload Integration Plan Annexes	**•Annex 3, Flight Operations Support:** •contains the customer inputs dealing with ground and onboard flight control operations and procedures. •topics covered include the payload operations support plan, payload flight operations decisions, payload operating procedures, hazardous command lists and checking, and payload operational flight schematics. **•Annexes 4-7** •do not apply to small satellites. **•Annex 8, Launch Site Support Plan (LSSP):** •provides data for planning launch site processing of the payload. •commits launch site facilities, support equipment, and services to the customer for a given time period. **•Annex 9, Payload Verification Requirements:** •JSC-140146, revision A, describes the activities necessary to determine interface compatibility of the payload with the STS. •includes any unique verification requirements and planning identified in the PIP agreements.
SDP	Safety Data Package	•provides framework for Payload Safety Review Panel (PSRP). •used to inform and justify to the PSRP that the intended payload design and operations comply with SSP system safety requirements. •provides a real-time safety reference document for use during ground and flight operations to help troubleshoot safety problems. •three copies are submitted 45 days in advance of a PSRP.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
SFP	Space Flight Plan	•listed on Muniz Payload Integration Schedule. •believed to be Air Force Documentation.
SIVP	Structural Integrity Verification Plan	•addresses the specific manner in which the various designs, analyses, and test requirements will be satisfied. •defines which of the documents and reports listed in the SIVP Deliverables will be required by the HH Project Office for review: **•<u>Analyses:</u>** •Detailed Stress Analysis including finite element model. •Fracture Control Analysis including certification of Nondestructive Evaluation (NDE) inspections. •Thermal Analysis. •Pressure Profile Analysis. **•<u>Test Reports:</u>** •Random Vibration Test. •Structural / Strength Qualification Test. •Modal Tests such as modal surveys, sine tests, etc. •Acoustic Test. •Mass Properties Measurements. •Thermal Test. **•<u>Miscellaneous:</u>** •Complete Parts and Materials List. •Complete Payload Assembly and Interface. •Control Drawings. •specific requirements waivable by HH Project Office. •only the applicable analyses and tests from above list should be included as deliverables in the structural integrity verification plan and report.

Table A-2. NASA Documents (cont.)

Document Number/ [Ref.]	Name	Purpose
SIVR	Structural Integrity Verification Report	•provided by the customer once the SIVP has been implemented. •presents the results of all analyses and test activities described in the verification plan. •due at L-13 months. •referenced in the Hazard Report section of the customer safety data submittal. •cross-referencing used to document completion of a particular hazard control verification activity.
STS SIP	STS Standard Integration Plan	•structured as a "blank book" to serve as a guide, or standard, for preparing the customer specific Payload Integration Plan (PIP). •contains the technical requirements, management interfaces, services, and schedules that are applicable to the class of payload involved.
SVTL/ [NSTS 13830]	Payload Safety Verification Tracking Log	•required to properly status the completion steps associated with hazard report verification items.

Table A-2. NASA Documents (cont.)

Another extremely important series of events in the preparation of documentation for payload launch on the STS are review panels. In most cases, the review panels require documentation prior to the meeting of the actual panel. The most notable review panel is the Safety Review Panel (SRP). The safety review panel assists the JSC NSTSO and the KSC Director of Safety in their responsibilities for safety. These panels are chaired by JSC and KSC, as applicable. They conduct the phased safety reviews during which all safety aspects of payload design, flight operations, GSE design, and ground operations are reviewed. The panels are normally conducted at four levels of payload design maturity but not all the reviews are mandatory. The depth and number of the formal reviews are determined by the STS safety review panel chairman in conjunction with the customer and depend on complexity, technical maturity, and hazard potential. The primary objectives of each of the safety review panel phases are listed in Table A-3 and are delineated extensively in the CARS document. [Ref. 3]

Phase	Time (Approx.)	Objectives
0	payload requirements review	•identify safety-critical subsystems, hazard groups, and applicable safety requirements for subsystems and associated ground operations.
I	payload preliminary design review	•assess the implementation approach, review hazards and resolution, and develop an understanding of verification approach.
II	payload critical design review	•verify design compliance with safety requirements and review verification methods.
III	payload hardware delivery	•validate the incorporation of all previous safety review agreements, ensure the satisfactory completion of all safety verification activities, and agree that all safety activities have been satisfactorily completed.

Table A-3. Safety Review Panel Phases

All documentation/data that is to be presented by the customer at each payload safety review panel must be submitted 45 days in advance. Data pertaining to payload design and flight operations should be sent to the Executive Secretary, NSTS Safety Panel, code NS2 at the Lyndon B. Johnson Space Center. GSE design and ground operations data is sent to Kennedy Space Center.

D. DOCUMENTATION REQUIRED BY DET 2

Documentation required by the Detachment 2 (Det 2) Space and Missile Systems Center (SMC) is best captured in their Program Introduction (PI) Supplemental Instructions. This document is used by Det 2 as a planning tool and any further information needed after analysis will be requested by Det 2. This preparation guide is broken down into several different sections and lists the documents by format number. Table A-4 lists each form and provides amplifying information in bullet format.

Format #	Purpose
1000	•contains the administrative portion of the document. •consists of program title, short title, key personnel and responsible agencies, security level, etc. •contains program identification information such as completion date, type of program, priority number, program status, contract number, contract terms, certification, etc.
1100	•discusses system background information such as mission duration and orbital life. •discusses system development milestones and phases. •contains test program and mission information and objectives.
1300	•spacecraft / payload information and other system characteristics. •discusses target characteristics if needed. •discusses electronic / electro-optical systems information.
1400	•lists all instrumentation which will emit and / or receive radio frequencies. •gives power outputs, known or proposed frequency utilization, and types of antennas to be used.
1500	•briefly discusses mission unique equipment or instrumentation to be operated by the program in connection with test operations.
1600	•lists the major events that will be performed in the overall test sequence.
1700	•discusses on-orbit test scenarios and timelines.
1800	•lists project materials, items, or test conditions which will present hazards to personnel or material through toxicity, combustion, blast, acoustics, fragmentation, electromagnetic radiation, radioactivity, ionization, or other means. •identifies where the hazards exist: pre-launch, launch, on-orbit, or re-entry. •lists of all on-orbit tests that are expected to produce debris.
2000	•describes the test operational concepts which will make the information in the remainder of the document more meaningful. •describes the roles of all participants. •lists desired roles and locations for all facilities participating in the test planning, execution, and post test data analysis and reduction.
2100-2300	•lists mission requirements for each mission phase such as pre-launch, launch, early orbit checkout, test planning, and test operations.
2500	•states requirements for support by Space Ground Link Subsystem (SGLS), unified S-band, RTS/CSTC recording systems, and user provided systems. •states purposes, time periods of coverage required, locations, and frequencies. •states whether the system(s) will be provided by the user or by the support agency.

Table A-4. DET 2 Documentation

Format #	Purpose
2600	•lists requirements for support of other special instrumentation not covered elsewhere.
2700	•describes ground communications support such as types, amounts, purpose and locations of terminals for test inter-communications, telephone, and voice recordings.
3000	•lists requirements for data assessment and command generation, software development, and whether support agency/user interface solutions will be required. •states locations and types of displays required. •states source of data, mission phases, and data rates if not indicated elsewhere.
3200	•lists weather forecast requirements.
3400	•lists other technical support requirements such as range ships, aircraft, etc.
4200	•lists the data types such as commands sent, vehicle health and status, sensor telemetry, etc. •defines data categories.
5000	•lists requirements for base facilities and logistics.
5300	•states the role of the Det 2 SMC Safety Office. •states whether Det 2 is required to support environmental and/or on-orbit safety studies.
5500	•specifies sources of routine maintenance for all mission unique equipment supplied by the customer.
6000	•lists other support required that is not covered in any other section.

Table A-4. DET 2 Documentation (cont.)

E. DOCUMENTATION REQUIRED BY THE FCC

The objectives of the PANSAT program are twofold:

- To provide NPS students with educational hands-on experience in the design, development and operation of a low cost amateur satellite.
- To provide the amateur radio community the opportunity to work with spread spectrum communications in a real time or store-and-forward mode. PANSAT is classified as an amateur platform. This allows PANSAT legitimate access to the amateur UHF frequency band for communications, experimentation and telemetry. [Ref. 5, p. 1]

As such, it will be necessary to undertake the process involved with licensing a satellite, which requires the formal request for and, hopefully, approval of an operating

frequency. This is accomplished by executing the appropriate procedures which are set by the Federal Communications Commission (FCC).

The FCC performs spectrum management, with satellite communications (i.e. PANSAT) being included in their realm of responsibility. NPS is currently pursuing licensing of PANSAT as an amateur satellite operating within the scope of the amateur satellite community. Table A-5 lists and provides a brief description of the FCC documents that are required as part of the licensing process.

FCC FORM/ [Reference]	**Name**	**Purpose**
FCC FORM 610 [Code of Federal Regulations (CFR), Title 47]	Application for Amateur Radio Station and/or Operator License	•first step in licensing a satellite is to obtain an individual amateur operator's license. •in most instances, the station license is obtained at the same time as the operator's license. •used to renew the trustee license. •used to change the individual station address.
FCC FORM 660 [CFR, Title 47]	Amateur License	•amateur operator license. •also lists the station license. •obtained pending successful completion of the pertinent parts of FCC FORM 610. •presently, licenses are valid for a period of ten years.
FCC FORM 610B [FCC Rule Book]	Application to Renew or Modify an Amateur Club, Races, or Military Recreation Station License	•used to renew any old club station licenses, if necessary.
FCC FORM 854 [FCC Rule Book]	Request for Approval of Proposed Amateur Radio Antenna and Notification of Action	•required if the antenna structure is more than 200 feet above the ground. •must also file **FAA FORM 7460-1** with the FAA. •special runway length and glide slope ratio rules exist which determine whether or not forms 854 and 7460-1 are necessary.

Table A-5. FCC Documentation

FCC FORM/ [Reference]	Name	Purpose
[CFR, Title 47, and ITU Radio Regulations]	Pre-space Operation Notification	•two required by the FCC prior to launch. •first notification must be submitted within 27 months of anticipated launch date. •consists of the space operation date, the satellite service area, orbital parameters and technical characteristics for both uplink and downlink. •second notification required to be sent to the FCC no later than five months prior to intended launch. •much like the first notification, but requests much more detail.
[CFR, Title 47, and FCC Rule Book]	In-space Notification	•must be submitted to FCC once the satellite has been successfully launched and it has started to transmit. •required within 7 days of commencement of satellite operations. •usually a resubmission of the second notification with all pertinent updates, such as the actual orbital parameters, as well as any last minute changes.
[CFR, Title 47, and FCC Rule Book]	Post-space Notification	•final notification required by the FCC. •written letter stating the termination of space operations and signal transmission. •should include the date time group of actual termination. •must be submitted within three months of termination of space operations. •if cessation of signal transmissions is ordered by the FCC, then post-space notification is required within 24 hours of termination.

Table A-5. FCC Documentation (cont.)

For future reference, once PANSAT is launched and operating, all spread spectrum communications must be documented by the ground station and retained for one year after the last transmission.

For FCC documentation, a normal delay time of five to six months from initial filing to publication of notification should be anticipated. When drafting these notices, the most current edition of the applicable references should be consulted, since federal rules and requirements involving this constantly evolving field occur on a continuous

basis; thus up-to-date references are an absolute necessity for the submission of accurate documentation. [Ref. 5, pp. 82-89]

F. HAM POLICY

In the FCC organizational structure, the private Radio Bureau exists to establish regulatory control over numerous types of radio stations including amateur stations. Satellites are looked at in the same manner as stations, and since PANSAT will operate in the amateur band, it will be considered an amateur station and will accordingly be licensed and regulated by the Private Radio Bureau of the FCC. [Ref. 5, p. 69]

PANSAT will be classified as an amateur satellite and when launched will operate within the scope of the amateur satellite community. Part 97 of Title 47 of The Code of Federal Regulations defines Amateur Service as:

> a radio communication service for the purpose of self training, intercommunication, and technical investigations carried out by amateurs, that is, duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

Part 97 of Title 47 further defines Amateur Satellite Service as "a radio communication service using stations on Earth satellites for the same purpose as those of the Amateur Service."

The FCC is responsible for the regulation of the amateur frequency bands within the United States, which is located in International Telecommunications Union (ITU) region 2. Specific portions of the Radio Frequency (RF) spectrum are authorized for use by the amateur radio community and in some instances this usage by amateurs is on a secondary basis only. Unfortunately, this means amateurs are not always protected from interference caused by primary users such as the U.S. Government.

PANSAT will operate in the UHF 70 cm band at a center frequency of 436.5 MHz, with approximately 2.5 MHz bandwidth. Satellite communications in this band are restricted to 435 to 438 MHz, which is a zone in the UHF spectrum available to the

amateur community. Title 47 of the CFR lists the sharing requirements for this band as follows:

- In adjacent ITU regions, frequency bands are allotted to different services of the same category, the basic principle is the equality of right to operate. Operations in one region should not interfere with the operations from another region.
- No amateur station transmitting in the 70 cm band may cause harmful interference to, nor is protected from interference from, the government radiolocation service.
- In Region II, the 430-440 MHz range is allotted to amateurs on a secondary basis. As such, they cannot cause interference to any other nation's radiolocation services.

Within each of the frequency bands, amateurs are restricted in the types of authorized emissions. Spread spectrum communications, which is the communications scheme to be used by PANSAT, is an authorized emission type in the 70 cm UHF band, but it cannot be used to encode a message and thereby preclude others from reading it. Facilitating communications is the goal and as such,

> NPS is required to make such things as schematics of PANSAT's encoder/decoder circuit boards public so that all interested amateurs may use the asset. These descriptions may be published in periodicals such as Orbit Magazine or the Amateur Satellite Report newsletter [Ref. 5, p. 82].

Only a relatively small percentage of amateurs are currently using amateur satellite services, but usage is expected to increase. According to the CFR, all persons desiring to become HAM operators and utilize satellite communications must follow the appropriate steps to obtain an individual amateur operator's license. The required licensing documents are listed and covered in the section preceding this one, entitled "Documentation Required by the FCC."

G. DOCUMENTATION RECOMMENDATIONS

Policy issues and documentation requirements are obviously quite extensive, with the underlying purpose being to assure the safe and orderly operation of the payload and

associated GSE. The safety issue, which is repeatedly and emphatically mentioned, reflects the increased awareness of the NSTS resulting from the STS-51L Challenger accident. Again, attention to detail is essential as well as instrumental in the quest to complete the documentation obligations.

Table A-6 is a PANSAT timeline based on a September 11, 1997, launch date.

Document	Prior to Launch	Tentative Due Date
DD Form 1721	L-30	14 Mar 95 - **C**
MOA	L-26	13 Jul 95 - **D**
SFP	L-25	14 Aug 95
NASA Form 1628	L-24	12 Sep 95 - **C**
PAR/CPR	L-24	12 Sep 95 - **D**
Payload Conference at GSFC	L-23	12 Oct 95
SDP-Flight (Prel)	L-20	12 Jan 96
SDP (including JSC Form 542B and JSC Form 542C)	L-20	12 Jan 96
Materials List	L-20	12 Jan 96
SIVP (including FCIP)	L-20	12 Jan 96
Failure Correction Panel	L-20	12 Jan 96
SDP-Grnd (Prel)	L-20	12 Jan 96
SDP-Flight (Ph 0/1)	L-20	12 Jan 96
SDP-Update (Ph 2)	L-19	12 Feb 96
SDP-Flight (Ph 2)	L-18	12 Mar 96
SDP-Grnd (Ph 2)	L-18	12 Mar 96
SRP-Flight (Ph 2)	L-16	13 May 96
SRP-Grnd (Ph 2)	L-16	13 May 96
PIP	L-16	13 May 96
CIR	L-14	12 Jul 96
SIVR	L-13	12 Aug 96
SDP-Grnd (Ph 3)	L-10	11 Nov 96
SRP-Grnd (Ph 3)	L-8	10 Jan 97
SDP-Final (Ph 3)	L-6	12 Mar 97
SDP-Flight (Ph-3)	L-5	14 Apr 97
SRP-Flight (Ph 3)	L-3	11 Jun 97
FRR	L-1	11 Aug 97
Launch	**L-0**	**11 Sep 97**

Legend: **C**=Completed
D=Drafted

Table A-6. PANSAT Documentation Timeline [Ref. 6]

Ideas/recommendations that could prove beneficial to the ongoing documentation effort and the overall PANSAT program include:

- when filling out documentation, ensure that the most current references are being utilized.
- keep copies of all submitted documentation.
- adhere to the master plan and do not allow documentation to be put off or ignored altogether.
- incorporate documentation requirements into the PANSAT Master Schedule, reflecting required due dates as they relate to the overall program and graphically portraying the documentation demands. This recommendation has already been incorporated.

Maximum utilization of available resources, timeliness, and adherence to established policy will help ease the strain of the painstaking paper chase known as documentation.

The list below signifies the documents that were not included on the timeline due to the fact that their definite due dates were vague or otherwise indiscernible. Due dates should be determined for these documents and they should then be added to the timeline.

- ICD - Interface Control Document
- JSC-21000-IAP - Integration Activities Plan
- JSC-21000-SIP-SML - STS Standard Integration Payload
- LSA - Launch Services Agreement
- MICD - Mechanical Interface Control Drawings

FCC documentation was not included in the timeline because, with the exception of the In-space and Post-space Notifications, it has already been completed. These two documents should be added to the PANSAT SCHEDULE so that they are not forgotten.

The SFP is listed on the Muñiz Engineering Payload and Integration Schedule, but amplifying information is nowhere to be found. This document is most likely generated by the Air Force, but further research is necessary to confirm authorship .

APPENDIX B. PANSAT PERSONNEL ROSTER

Table B-1 lists the personnel presently involved with the PANSAT project.

Faculty Advisor	Title/Area of Expertise
Rudy Panholzer	SSAG Chairman; Principal Investigator (PI); PM
Michael Ross	Project Lead
Barry Leonard	System Design
Randy L. Borchardt	Communications Payload & Electrical Engineering (EE) Theses Coordinator
Dick Adler	Antenna Design
Terry Alfriend	Orbit and Attitude Dynamics
Bob Ashton	Electric Power
Doug Fouts	System Design; Point of Contact - Amateur Radio Users
Alan Kraus	Thermal Analysis
Sherif Michael	Solar Array
Sandi Scrivener	Structures
Fred Terman	Digital Control
SSAG Engineering Staff	**Title/Job Description**
Dan Sakoda	Systems Engineer; Mission Analysis/Design; S/C Configuration/Structure; S/C Operations/Analysis
David Rigmaiden	Communications Subsystem Coordination; Launch Field Operations
Ron Phelps	Electric Power Subsystem Coordination; Elect. Subsystems Interface Control Document (ICD)
Todd Morris	Systems Engineering Master Plan/Documentation; Systems Level Test Coordination; S/C Configuration/ Structure
Jim Horning	Digital Control Subsystem (DCS) Coordination; S/W Architecture, Design & Documentation; Subsystems S/W Design/Coding/Test
Glenn Harrell	Master Model Maker: Machining & Fabrication
Gian Duri	Coordination of Project Planning; Scheduling/Control; Functional Requirements Document

Table B-1. PANSAT Personnel Roster

APPENDIX C. PANSAT AND PRE-PANSAT THESES LISTS

Table C-1 is a chronological listing of completed theses that pertain to PANSAT. The first column is a running tally of the total number of PANSAT-related theses, followed by columns that provide the respective completion dates, authors, advisors, and titles.

Number	Date	Author	Advisor(s)	Title
	1989			
1	Mar.	Hiser, James K.	Cotton	"Design of a Reliable Computing System for the Petite Amateur Navy Satellite (PANSAT)"
	1990			
2	Jun.	Noble, Michael L.	Ewing	"Preliminary Design of the PANSAT Electrical Power Subsystem"
3	Jun.	Paluszek, Stephen E.	Wadsworth	"Spread-Spectrum Communications for the Petite Amateur Navy Satellite (PANSAT)"
4	Sep.	Rowsey, Robert R.	Panholzer	"Design Restrictions and Licensing for Petite Amateur Navy Satellite (PANSAT)"
5	Dec.	Tobin, Stephen M.	Cotton	"Construction and Testing of an 80C86 Based Communications Controller for the Petite Amateur Navy Satellite (PANSAT)"
	1991			
6	Jun.	Ellrick, Daniel A.	Adler	"An Antenna Design for PANSAT Using NEC"
	1992			
7	Sep.	Gottfried, Russell	Bailey	"PACSIM: Using Simulation in Designing a Communications Satellite"
8	Sep.	Payne, Robert A. Jr.	Wight	"Applications of the Petite Amateur Navy Satellite (PANSAT)"
9	Sep.	Sakoda, Daniel J.	Kolar	"Structural Design, Analysis, and Modal Testing of the Petite Amateur Navy Satellite (PANSAT)"
10	Sep.	Sityar, Irma	Wight	"Sun Sensor Implementation Using Solar Power Arrays"
11	Dec.	Fritz, Thomas M.	Tri Ha	"A Biphase Shift Keying (BPSK), Direct Sequence, Spread Spectrum Modem for Petite Amateur Navy Satellite (PANSAT)"
	1993			
12	Mar.	Ashe, John D.	Wight	"Petite Amateur Naval Satellite Spacecraft Digital Control System: A Hardware Design"

Table C-1. PANSAT Theses List

Number	Date	Author	Advisor(s)	Title
	1993			
13	Mar.	Murray, Terrence J.	Tri Ha	"Four Frequency-Shift Keying (4-FSK) Spread Spectrum Modulator and Demodulator"
14	Sep.	Brown, Arnold O., III	Tri Ha	"Communications Subsystem for the Petite Amateur Navy Satellite (PANSAT)"
	1994			
15	Mar.	Ford, Teresa O.	Fouts	"Preliminary Flight Software Specification For The Petite Amateur Navy Satellite (PANSAT)"
16	Mar.	Hand, Gregory F.	Ashton	"Intermediate Design and Analysis of the PANSAT Electrical Power Subsystem"
17	Mar.	Lawrence, Gregory W.	Ross	"Preliminary PANSAT Ground Station Software Design and Use of an Expert System to Analyze Telemetry"
18	Mar.	Leu, David L.	Wight	"Preliminary Digital Control System Design For The Petite Amateur Navy Satellite (PANSAT)"
19	Jun.	Cuff, Daniel J.	Ross	"Lifetime and Reentry Prediction for the Petite Amateur Navy Satellite (PANSAT)"
20	Jun.	Victor, Eric	Ross	"Thermal Analysis of PANSAT Electric Power Subsystem"
21	Sep.	Gannon, Brian B.	Scrivener	"Design and Analysis of the Launch Vehicle Adapter Fitting for the Petite Amateur Navy Satellite (PANSAT)"
22	Sep.	O' Neal, Stephanie	Ross	"A Procedure for Accessing Digital Satellites Containing Amateur Payloads"
23	Sep.	Patterson, Sheila	Ross	"Thermal Analysis of PANSAT Batteries and Electrical Power Subsystem"
24	Sep.	Rich, Markham K.	Ross	"A Systems Analysis and Project Management Plan for the Petite Amateur Navy Satellite (PANSAT)"
25	Sep.	Weiding, David B. and Finnegan, Michael P.	Panholzer	"Development of the Communications System for the Petite Amateur Navy Satellite (PANSAT)"

Table C-1. PANSAT Theses List (cont.)

Number	Date	Author	Advisor(s)	Title
	1994			
26	Dec.	Calvert, Thomas C.	Panholzer	Computer Interface Development for the Petite Amateur Navy Satellite (PANSAT) Simulator
27	Dec.	Huneke, Stephen P.	Fouts	"The Design of a Digital Direct Sequence Spread Spectrum Demodulator for the Petite Amateur Navy Satellite (PANSAT)"
	1995			
28	Mar.	Oechsel, Craig R.	Wight	"Implementation of Error Detection and Correction (EDAC) In The Static Random Access Memory (SRAM) Aboard The Petite Amateur Navy Satellite (PANSAT)"
29	Jun.	Eagle, Peter A.	Borchardt	"The Design of an Amateur Radio Interface for Modulation and Demodulation of Petite Amateur Navy Satellite (PANSAT) Communications"
30	Jun.	Karapinar, Ercument	Adler	"Modification and Verification of an Antenna Design for the Petite Amateur Navy Satellite (PANSAT) Using NEC"
31	Jun.	Tackett, Steve	Scrivener	"Design And [Structural] Analysis Of EPS Housing And Circuit Boards For PANSAT"
32	Sep.	Alldridge, David	Leonard	"Critical Failure Mode Analysis of the Petite Amateur Navy Satellite (PANSAT)"
33	Sep.	Bible, Steven R.	Lundy	"Design and Implementation of a World Wide Web Amateur Satellite Ground Station Gateway"
34	Sep.	Davinic, Nick	Kraus	"Evaluation of the Thermal Control System of the Petite Amateur Navy Satellite (PANSAT)"
35	Sep.	Dawson, David	Borchardt	"The Design of a Direct Sequence Spread Spectrum Code Division Multiple Access Environment Simulator"
36	Sep.	Nichols, Troy	Ross	"A Description of the PANSAT Command Language"

Table C-1. PANSAT Theses List (cont.)

Number	Date	Author	Advisor(s)	Title
	1995			
37*	Sep.	Gericke, Olaf	Panholzer	"Design and Analysis of the Housing of the Communication Payload of the Petite Amateur Navy Satellite (PANSAT)"
38*	Sep.	Hengst, Michael	Panholzer	"Development of a Computer-Controlled Instrumentation for a Thermal-Vacuum Chamber"
39*	Sep.	Bartschat, Jens	Panholzer	"Design and Implementation of the PANSAT Software Ground Station"
40	Dec.	Severson, Fred J.	Ross	"An Overview of the Petite Amateur Navy Satellite (PANSAT) Project"

Table C-1. PANSAT Theses List (cont.)

*Denotes special theses written by German officer students in fulfillment of the requirements for a *Diplomarbeit* from the *Universitat der Bundeswehr Muenchen*..

Table C-2 is a chronological listing of pre-PANSAT theses. These theses preceded the current generation of theses that directly relate to PANSAT and have been instrumental in the evolution of the present-day program. Columns provide the completion dates, authors, and titles.

Date	Author	Title
1987		
Dec.	Chappell, David C.	"Preliminary Design of the ORION Attitude Control System"
Dec.	Schroeder, Douglas S.	"Application of ORION to Navy UHF Satellite Communications"
Sep.	Peters, David L.	"Investigation of Design Considerations for Telemetry, Tracking and Command (TT&C) Antenna System on Naval Postgraduate School ORION Mini-Satellite"
Sep.	Welch, William J., and Landers, Mark F.	"Project Skylite: A Design Exploration"
1988		
Dec.	Heinz, Karl R.	"The Application of Brian's Method to the Solution of Transient Heat Conduction Problems in Cylindrical Geometries"

Table C-2. Pre-PANSAT Theses List

Date	Author	Title
1988		
Dec.	Dee, Suzanne M.	"Design of a Three-Axis Stabilized ORION Satellite Using an All-Thruster Control System"
Sep.	Lyon, David C., and Cipollone, Lawrence V.	"Space Launch Vehicle Alternatives for Small Satellites and the Current Commercial, Political and Physical Environments"
Sep.	Watson, John A.	"Transient Three-Dimensional Heat Conduction Computations Using Brian's Technique"
Jun.	Smith, Mark B.	"Design Investigation for a Microstrip Phased Array Antenna for the ORION Satellite"
Jun.	Sage, Scott E.	"Total Dose Radiation Effects on Bipolar Composite and Single Operational Amplifiers Using a 30 MeV Linear Accelerator"
Mar.	Boyd, Austin W., Jr.	"Design Consideration for the ORION Satellite: Structure, Propulsion, and Attitude Control Subsystems for a Small, General Purpose Satellite"
1989		
Mar.	Cunningham, Janet L.	"Spin Stabilization of the ORION Satellite Using a Thruster Attitude Control System with Optimal Control Considerations"
Mar.	Boyd, Frank W.	"Consideration of Gravity Gradient Stabilization for ORION"

Table C-2. Pre-PANSAT Theses List (cont.)

APPENDIX D. WHERE TO LOOK FOR AMPLIFYING INFORMATION

A plethora of documents concerning PANSAT exists, rendering the research process for any particular aspect of the satellite or its associated program somewhat time-consuming and tedious. The purpose of Table D-1 is to provide guidance for further research by listing sources that an interested party might find helpful in their quest for amplifying information. The format follows the table of contents, with the authors of relevant theses listed in the second column and related publications/documents listed in the third column. This information supplements the list of references.

TOPIC	AUTHORS OF RELEVANT THESES	RELATED PUBS./DOCS.
Introduction		
What is PANSAT?	All theses	AIAA 93-4211 - Horning, Jim A.
Requirements and Constraints	Rich, Gannon, Payne	Requirements Doc.
Objectives	Payne, Rich, Bible	
Facilities	Sakoda, Bailey	PANSAT Facilities Document - Sakoda
Management and Organization	Rich	
Student Involvement/SS4003	Rich	NPS Catalog
External Resources/Interfacing	Rowsey	
Space Test Program (STP)		See Note 1
Federal Comms. Commission	Rowsey	Code of Federal Regulations
Detachment 2		Space Test and Evaluation Detachment 2, SMC Information Pamphlet
Supporting Activities	Rowsey	Davidoff, Martin R., *The Satellite Experimenter's Handbook*, ARRL, 1985.
History	Gannon	"Petite Amateur Navy Satellite (PANSAT)," paper by Sakoda, Daniel, and Hiser, J. K.

Table D-1. Where to Look for Amplifying Information

TOPIC	AUTHORS OF RELEVANT THESES	RELATED PUBS./DOCS.
User Operations Introduction	Bible	
Communications Window	Bible, Sakoda, Eagle, Cuff, Rich	AIAA 93-4229 - Sakoda, Daniel
User Ground Station Operations	Bible, Payne	AIAA 93-4211 - Horning, Jim A.
Direct Sequence Spread Spectrum Overview	Weiding, Fritz, Paluszek, Huneke	
General PANSAT Description	All theses	PANSAT Engineering Docs.
Physical Description	Weiding	
Subsystems	All theses	
Structure Subsystem	Sakoda, Gannon, Tackett, Gericke	
Electrical Power Subsystem	Hand, Noble	AIAA 93-4229 - Sakoda, Daniel; PANSAT Systems Analysis Group Sys. Rev., AA4831 Class Proj., Spring 1994.
Communications Subsystem	Weiding, Leu, Brown, Paluszek, Cuff	AIAA 93-4229 - Sakoda, Daniel; PANSAT Systems Analysis Group Sys. Rev., AA4831 Class Proj., Spring 1994.
Digital Control Subsystem	Ashe, Leu	AIAA 93-4229 - Sakoda, Daniel; "PANSAT Test Plan"-Morris, Todd; PANSAT Systems Analysis Group Sys. Rev., AA4831 Class Proj., Spring 1994.
Thermal Control Subsystem	Victor, Patterson, Davinic	
Software	Ford, Lawrence, Nichols, Bartschat	AIAA 93-4211 - Horning, Jim A.

Table D-1. Where to Look for Amplifying Information (cont.)

TOPIC	AUTHORS OF RELEVANT THESES	RELATED PUBS./DOCS.
Testing	Rich, Sakoda	See Note 2
Command Ground Station	Bible, O'Neal, Rich, Lawrence	AIAA 93-4211 - Horning, Jim A.; PANSAT Systems Analysis Group Sys. Rev., AA4831 Class Proj., Spring 1994. de Leon, Arthur, "PANSAT: An Educational Tool for Space Systems Operations Curriculum," AA4830 Term Paper, Dec. 2, 1994.
Launch Options	Payne, Sakoda	
Space Shuttle	Payne, Sakoda, Cuff	"PANSAT Test Plan" - Morris, Todd
Small Self-Contained Payload (SSCP)	Payne, Sakoda, Gannon	Sampson, H. T., "Experimenter's Planning Guide for DOD STP", Aerospace Report No. TOR-94(4508)-1
Release Point in Orbit	Payne, Cuff	
Minuteman II/III		Multi-Service Launch System Presentation Booklet
On-Orbit Operations	Rich, Cuff	
Operating Procedures	Rich	Final Report of the First Annual Mission Operations Working Group (MOWG) for the Petite Amateur Navy Satellite (PANSAT), AA4831 Class Project, June, 1995.
PANSAT Orbital Decay	Cuff	"PANSAT Orbit Decay Analysis and Ground Station View" - Sakoda, Daniel

Table D-1. Where to Look for Amplifying Information (cont.)

TOPIC	AUTHORS OF RELEVANT THESES	RELATED PUBS./DOCS.
Reentry	Cuff	Refling, O., Stern, R., and Potz, C., "Review of Orbital Reentry Risk Predictions", ATR-92 (2835)-1, The Aerospace Corporation
Structural Failure and Survivability to Impact	Cuff	Refling, O., Stern, R., and Potz, C., "Review of Orbital Reentry Risk Predictions", ATR-92 (2835)-1, The Aerospace Corporation
Budget Information		PANSAT Budget Spreadsheet, Duri, Gian
Recommendations/Conclusions	Payne, Rich	
Policy and Documentation - Appendix A		See Note 3

Table D-1. Where to Look for Amplifying Information (cont.)

Note 1: STP

Sampson, H. T., "Experimenter's Planning Guide for DOD STP," Aerospace Report No. TOR-94(4508)-1

Space Test Program Overview Document

The Aerospace Corporation, Report No. TOR-0091(6508-05)-1, *Experimenter's Planning Guide for Department of Defense Space Test Program*, by F. L. Knight and H. T. Sampson, 8 June 1991.

Note 2: Testing

Electromagnetic Compatibility Requirements for Space Systems, MIL-STD-1541B

Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, MIL-STD-461C.

Environmental Test Methods and Engineering Guidelines, MIL-STD-810E.

Experimenter's Planning Guide for Department of Defense Space Test Program, Knight and Sampson, The Aerospace Corporation.

General Environmental Verification Specification for STS Payloads, Subsystems, and Components, GEVS-STS, Goddard Space Flight Center.

Hitchhiker Customer Accommodations and Requirements Specifications, HHG-730-1503-07, GSFC, 1994.

Morris, Todd, "PANSAT Test Plan," SSD-TP-PA002, June 20, 1994.

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Safety Policy and Requirements for Payloads Using The Space Transportation System (STS), NASA NHB 1700.

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<u>Note 3: Policy and Documentation</u>

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JSC-21000-IAP: Shuttle/Payload Integration Activities Plan, Sep. 1985.

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NASA Small Self-Contained Payload Program Get Away Special, Payload Number G 337, Payload Accommodations Requirements Document, 18 Jan 89.

NSTS 1700.7B: Safety Policy and Requirements for Payloads using the STS, January 1989.

NSTS 13830 (Revision B): Implementation Procedure for STS Payload System Safety Requirements.

Payload Integration Schedule, PANSAT STS-86, Muñiz Engineering Inc., Mar. 15, 1995.

Rowsey, Robert R., *Design Restrictions and Licensing for Petite Amateur Navy Satellite (PANSAT)*, Master's Thesis, Naval Postgraduate School, Monterey, CA, Sep. 1990.

Sampson, H. T., *Experimenter's Planning Guide for Department of Defense Space Test Program*, Aerospace Report No. TOR-94(4508)-1, July 1995.

Title 47 of The Code of Federal Regulations, Government Printing Office, 1989.

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9. Horning, J. A., "Navy Education Through Amateur Satellite Development," AIAA 93-4211, Naval Postgraduate School, Monterey, CA.

10. Private conversation with Professor Steve Garret, 7 Aug, 1995. (814-863-6373)

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